JOINTING PATTERNS IN THE AREA

OF THE HOCKING HILLS

STATE PARKS, OHIO

SENIOR THESIS

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ABSTRACT

Jointing in shales and sandstones in eastern Ohio was formerly believed capable of forming only haphazard nonsystematic joint orientations. This paper presents evidence that jointing in sandstone in Hocking County, southeastern Ohio, exhibits a regional pattern which is related to systematic jointing surrounding the Appalachian axial trend in Pennsylvania. These joints control the direction of stream drainage patterns and hence the development of topographic features in the Hocking Hills State Parks, further indicating their regional significance.

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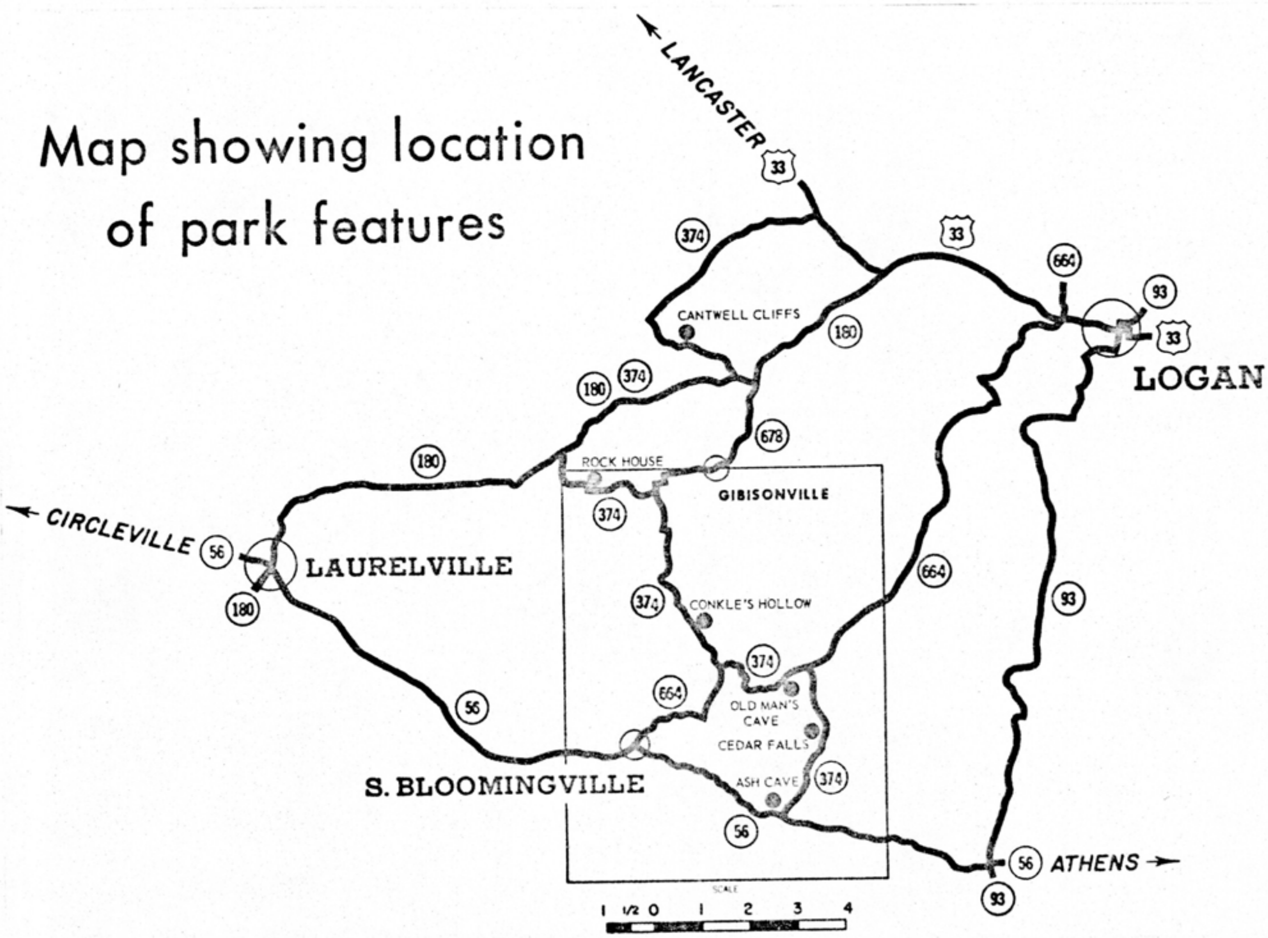
INTRODUCTION OF TOPIC

The possibility that landscape features in the area of the Hocking Hills State Parks were formed because of patterns of regional jointing first occurred to the writer after observing similarities in trends of several major joints while participating in a geomorphological field trip in this area during the spring of 1973. Wishing to pursue this matter further, permission was obtained to undertake this project as a senior research thesis.

The purpose of this study is threefold: first, to examine the literature on the structural origin of joint formation in the Appalachian Plateau region and determine if the origin of the jointing in the Hocking Hills State Parks, which border the plateau, is structurally related to Pennsylvania regional joint patterns, or are dependent upon Appalachian compressive folding; secondly, to collect data on joint bearings, their patterns and physical features, and their structural relation to the rock units; third, to draw conclusions about the joint patterns in the Hocking Parks area and their influence in shaping the topography.

AREA OF STUDY

The six Hocking Hills State Parks are in Benton and Laurel Townships of Hocking County in southeastern Ohio, south of Lancaster and west of U.S. 33 and Logan along State Routes 664 and 374. In the Parks region, exposed as large outcrops, cliffs, and caves, is the Black Hand Sandstone Member of the Cuyahoga Formation. These cliffs, forested hollows, and overhanging ridges with waterfalls are scenic in their beauty and were set aside as State Parks in the 1920's. The only previous joint study near this area was by Karl Ver Steeg in 1942 and 1944, when he measured the jointing trends in coal beds throughout eastern Ohio.



METHOD OF STUDY

The fieldwork consisted of taking attitude bearings on as many joints as feasible in a locality and noting depth of fracture, size, and location of jointing in relation to topography. Aerial photos were also used. All the joints measured were exposed in the Black Hand sandstone, since this member is the major lithologic unit in the Hocking Hills State Parks and the only one which contains good exposures of jointing. Joints were measured to within one degree, and since most were vertical, dips were not recorded. Compilation of data is presented in rose diagrams and maps associated with the description of field areas.

For the purpose of this study a joint will be defined as a fracture in rock along which there has been no apparent movement parallel to the surface of the break (Chapman, 1958, p. 552; Billings, 1973, p. 140).

Fieldwork was carried out during November and December, 1973.

ACKNOWLEDGEMENTS

For valuable criticism and suggestions in preparing this paper, I wish to thank Dr. Sidney E. White, and for assistance with questions concerning the principles of jointing, I wish to thank Dr. George E. Moore. I am also thankful for the time-saving help in research provided by Geology librarian, Ella Slifko. I am indebted to Martin Kopacz for his critical review of this work, and to Jeff Reese for his technical assistance. Finally, I am greatly indebted to Michael Costello and Jeffrey Smith for their assistance in the fieldwork and for providing the proper encouragement and motivation to complete this study.

JOINTING PATTERNS IN THE AREA OF THE HOCKING HILLS STATE PARKS, OHIO

CHAPTER 1

REGIONAL JOINTING PATTERNS

The Hocking Hills State Parks are on the western edge of the Appalachian Plateau and therefore are structurally more influenced by the Permian Appalachian Mountain axial folding and associated jointing than by the Upper-Cambrian Cincinnati Arch to the west.

Jointing in the Appalachian Plateau Province is complex, but data recently compiled in Pennsylvania by Nickelsen and Hough has brought several regional jointing patterns into focus. According to Nickelsen and Hough (1967, p.609), "the basic unit of jointing is the fundamental joint system, comprised of an approximately orthogonal systematic and nonsystematic set of joints." Intersection between these systematic and nonsystematic joint sets commonly approaches 90 degrees, while more complex patterns of jointing result from overprinting of two or more fundamental systems. (Nickelsen and Hough, 1967, p. 625; Chapman, 1958; p.

552; Billings, 1973, p. 156). These definitions will be employed in the following summation of Appalachian regional jointing.

"Systematic joints in shales and sandstones are usually planar or broadly curved surfaces occurring in parallel sets which continue across other intersect joint sets." (Nickelsen and Hough, 1967, p. 613). In coals, they are the face cleats. In most cases systematic joints possess oriented surface structures, such as plumose markings, and are perpendicular to the upper and lower boundaries of the rock units in which they occur (Hodgson, 1961a, p. 12-13). Nonsystematic joints include non-planar joints in shales and sandstones and the butt cleats in coals. These curved fractures meet but do not cross other systematic or nonsystematic joints, usually terminate against bedding planes, and do not show oriented surface structures (Nickelsen and Hough, 1967, p. 614; Hodgson, 1961a, p. 13). When approximately normal to systematic joints, they are named truncated joints.

Jointing characteristics of coals, shales, and sandstones may vary slightly because of the different fracturing properties of these rocks. Systematic joints in shales and sandstones trend parallel to each other and display similar planeness, but are more widely spaced in sandstone. More frequent coal joints, formed first because they withstand less stress (Price, 1959, p. 162), develop an independent initial pattern that may vary 25-30 degrees from shale and sandstone joints (Nickelsen and Hough, 1967, p. 610). But later stresses that produce the dominant fracturing in shales and sandstones passes down into the coals, overprinting and reorienting the coal fractures to the prominent shale and sandstone orientation. If the stress axes have not been disturbed between fracture periods, the joint orientations (Fig. 1 and 2) will be essentially the same for all three rock types (Nickelsen and Hough, 1967, p. 615).

The work in western Pennsylvania and central New York by Nickelsen and Hough deals with the intersection patterns of orthogonal systematic and nonsystematic joints and their structural relationship to the Appalachian fold axes. The origin and effect of the forces involved in creating the joint patterns and forming the Appalachian axial trend is also discussed. As the fold axes bend from N.30°E. in the southern portion of Pennsylvania to N.70°E. in the northeast, Nickelsen and Hough discovered that most systematic joints in shale and sandstone strike northwest and intersect the fold axes transversely at large angles. As the axial trace changes orientation throughout the region, the strike of the joint sets does not change to remain normal to the fold axes. This indicates that the strike of the joint sets is more persistent than the strike bearing of the associated folds and that no definite constant angular relationship exists between one joint set and the associated fold axes. Rather, "the regional joint pattern consists of overlapping joint sets of remarkably uniform orientation, each joint trend being locally dominant where it is most nearly perpendicular to the fold axes." (Nickelsen and Hough, 1967, p. 609). During this transition a dominant joint set is intersected by and eventually replaced by another joint set of similar strike but more nearly perpendicular to the fold axes. (Fig. 3) (Nickelsen and Hough, 1967, p. 618-620).

Thus Nickelsen and Hough have shown that systematic jointing patterns are not directly related to nor dependent upon the axial trend of the major structural feature in this area. Because systematic

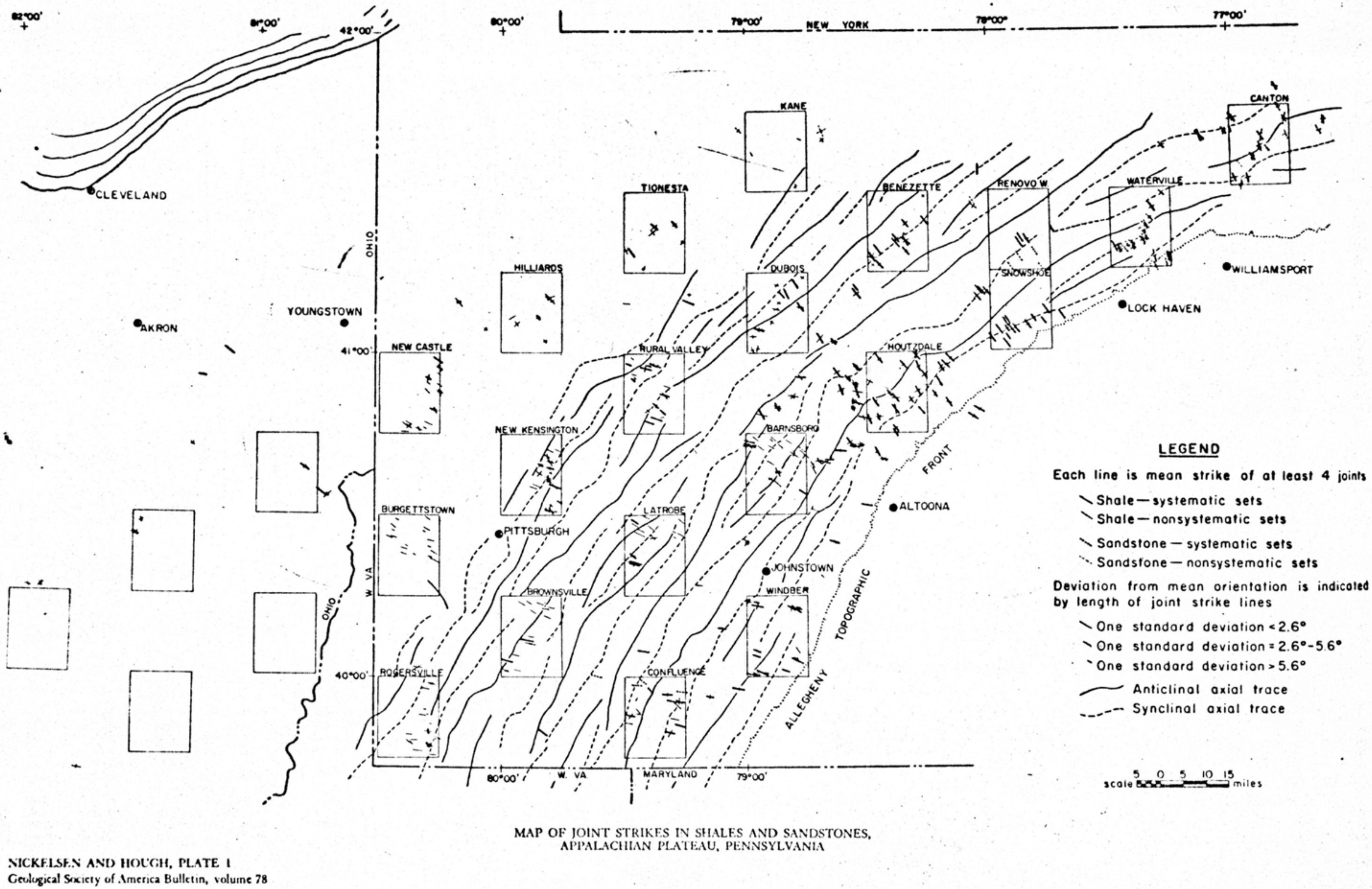
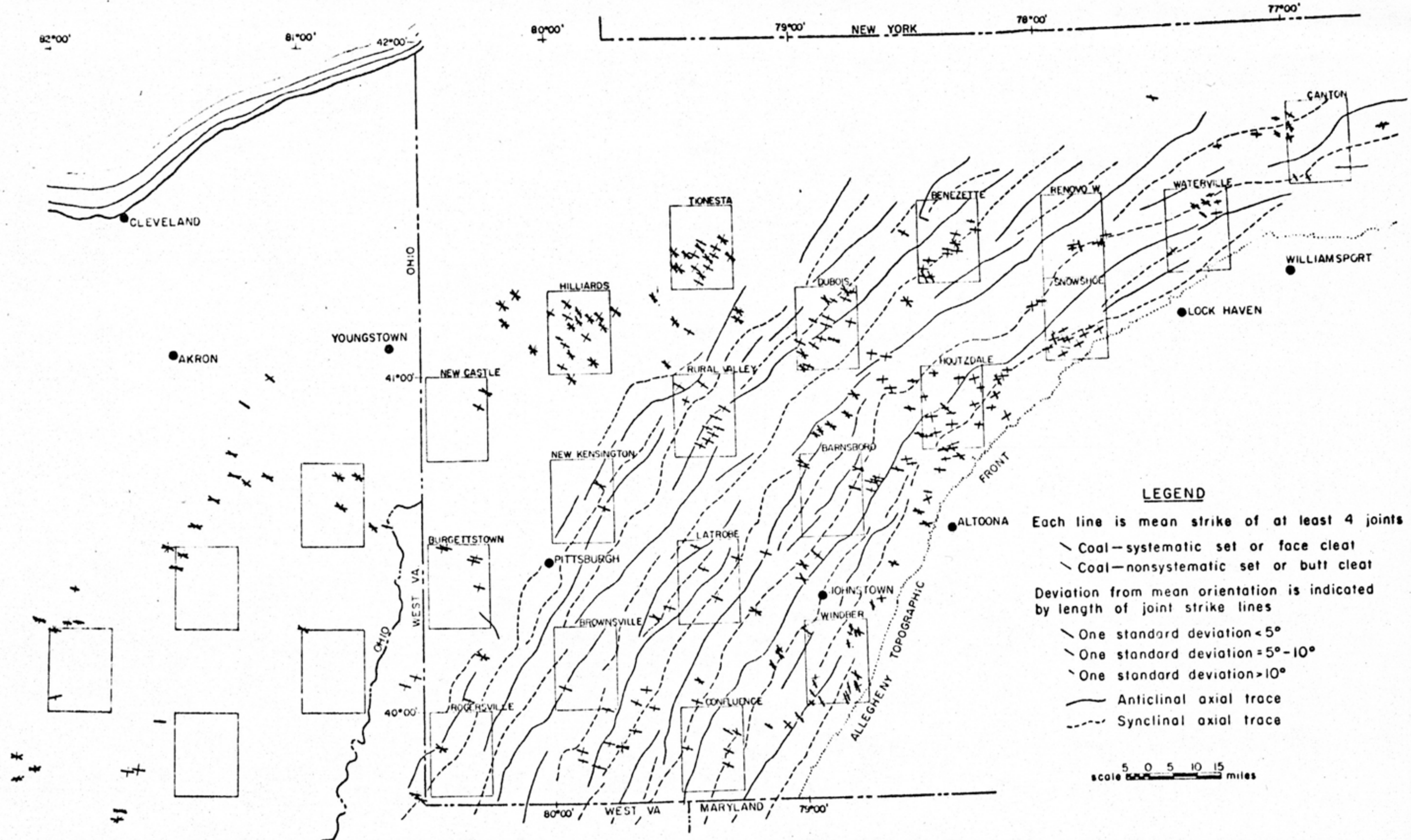


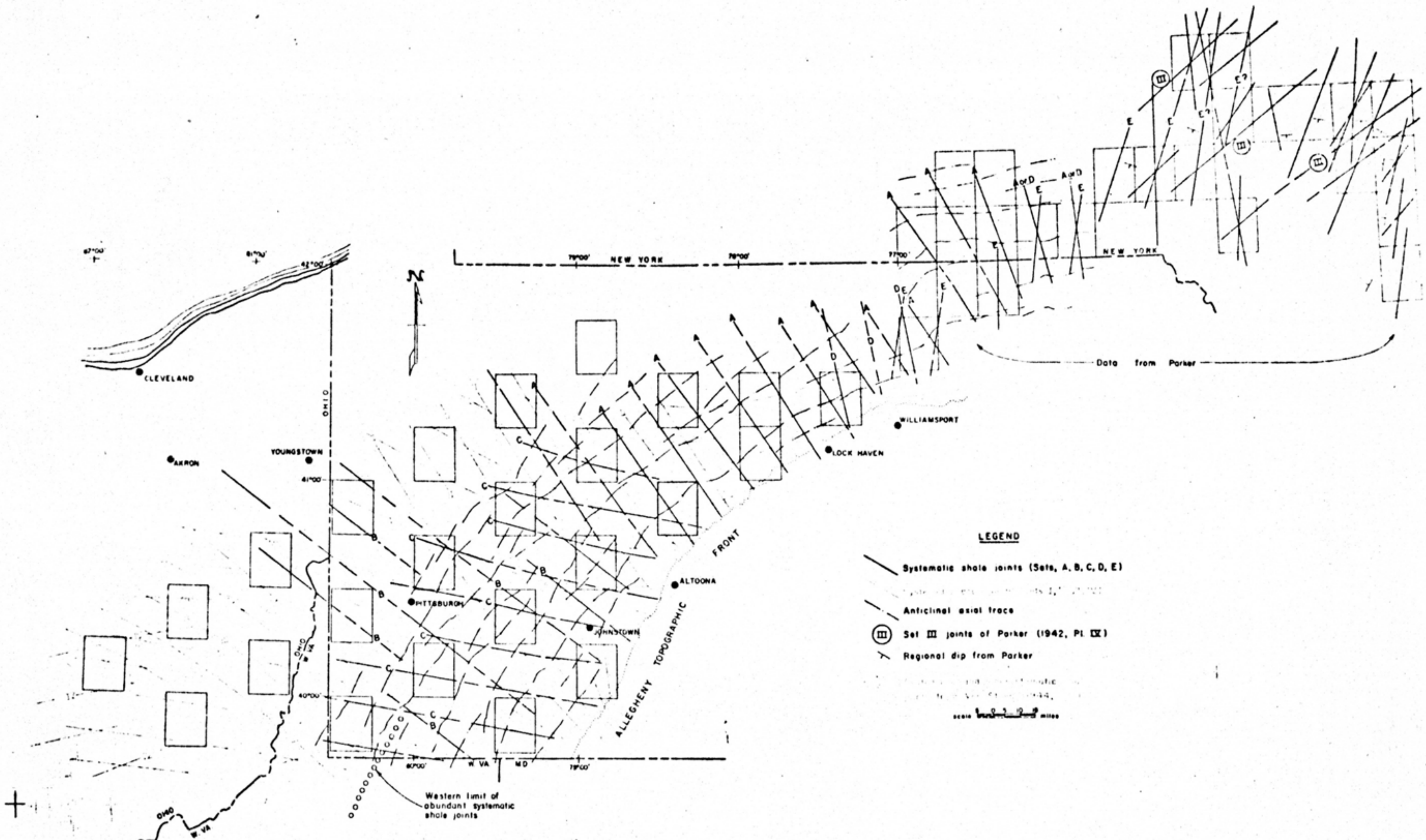
Figure 1. From Nickelsen and Hough, GSA Bulletin, V.78, plate 1. Map of joint strikes in shales and sandstones, Appalachian Plateau, Pennsylvania. Cross in lower southwest corner locates Hocking Hills State Parks.



MAP OF JOINT STRIKES IN COALS, APPALACHIAN PLATEAU, PENNSYLVANIA

NICKELSEN AND HOUGH, PLATE 2
Geological Society of America Bulletin, volume 78

Figure 2. From Nickelsen and Hough, GSA Bulletin, V.78, plate 2. Map of joint strikes in coals, Appalachian Plateau, Pennsylvania. Cross in lower southwest corner locates Hocking Hills State Parks.



INTERPRETED SYSTEMATIC SHALE AND COAL JOINT PATTERN OF
THE APPALACHIAN PLATEAU OF PENNSYLVANIA, NEW YORK, AND OHIO

NICKELSEN AND HOUGH, PLATE 3
Geological Society of America Bulletin, volume 78

Figure 3. From Nickelsen and Hough, GSA Bulletin, V.78, plate 3. Map of interpreted systematic shale and coal joint pattern of the Appalachian Plateau of Pennsylvania, New York, and Ohio. Cross in lower southwest corner locates Hocking Hills State Parks.

joints are transverse to the fold axes, but do not change orientation to maintain constant angular relationships to fold axes as the axes bend throughout the region, Nickelsen and Hough (1967, p. 627) have concluded that the joints in shale formed earlier than the folding, but are still related to the same stress increase that later cause the Appalachian folding. As the joint sets and fold axes change toward the northeast, around the Hudson River area, systematic joints of similar orientation strike nearly parallel to the fluctuating fold axes. But moving westward through Pennsylvania, perpendicular relationships between the northwest strike of the systematic joints and the N.30°E. trend of the fold axes are dominant. South of Pennsylvania the axial trace approaches north-south and the corresponding joint sets almost east-west.

The origin of systematic jointing in western Pennsylvania is due to northwest-southeast horizontal compressive forces that formed extension fractures perpendicular to the direction of least compression. In this region the axis of least compression is the trace of the Appalachian fold axis. These joints were formed near the close of the Permian, but before Appalachian folding occurred (Nickelsen and Hough, 1967, p. 624-626; Parker, 1942, p. 392, 398). The prevalence of the orthogonal relationship between systematic and nonsystematic joint sets means that if systematic joints are considered to be extension fractures, then nonsystematic joints, formed at right angles to the northwest-southeast greatest principal stress axis after pressure is released, are a special type of extension fracture, termed a release fracture. This is a post-compressive jointing resulting from a combination of residual tectonic and surficial stress differences arising locally due to erosion and unloading (Nickelsen and Hough, 1967, p. 609, 626-627; Billings, 1973, p. 156-157, 168; Chapman, 1958, p. 552, 556).

There is little evidence to indicate sheer fractures along the axial trace. Sheering may be present, but most exposures express only the joint set most perpendicular to the axial trace as a systematic extension fracture. Fundamental sets do not contain both sheers because it is impossible to pair up joint sets and stresses. The apparent conjugate sheet fractures result from the overlap of two separate systematic sets of different orientations from adjacent areas along the fold axes (Nickelsen and Hough, 1967, p. 622, 624-625).

The compressive stress essential for producing regionally oriented systematic joints in shales and sandstones related to the systematic joint sets in Pennsylvania and to the Appalachian fold trends was never attained in eastern Ohio, as indicated by the dying out of developed patterns of systematic jointing (Nickelsen and Hough, 1967, p. 626). Moving westward from the Appalachian Plateau core, structural force declined, thus creating a decrease in jointing frequency and size, while increasing the spacing interval. In eastern Ohio, therefore, only scattered systematic jointing occurs. Regional systematic jointing sets in shale and sandstone are largely restricted to the eastern Appalachian Plateau within sixty miles of the Allegheny Topographic Front (Fig. 3), although a few isolated localities exist further west. Small, less-planar nonsystematic joints, consisting usually of two or more equally expressed perpendicular intersecting joint sets are considered to be western equivalents of these systematic joints as far as 100 miles west of the Allegheny Front. Farther west, Nickelsen and Hough (1967, p. 620) hypothesize that nonsystematic joints become haphazard in orientation.

This writer disagrees with this conclusion and will present evidence indicating that nonsystematic joints in eastern Ohio do have a regional trend related to the orientation and stresses of systematic jointing found in Pennsylvania.

JOINTING PATTERNS IN EASTERN OHIO

Although shales and sandstones in eastern Ohio do not show systematic patterns because of the greater forces it takes to fracture them, Ver Steeg has shown that the easily fractured coals show local persistence of joint strikes and prominent systematic orientations throughout this area, and into central Ohio. Eastern Ohio is apparently west of the major stresses that formed the Appalachian folding, but by drawing a broad, unsymmetrical curve, convex side to the west, perpendicular to the strike axis of Ver Steeg's coal joint patterns (Fig. 4), the trace of this arc will parallel the Appalachian axial trend at the same latitude, and a regional change in orientation of the dominant set of coal strike joints will remain perpendicular to the axial trend (Ver Steeg, 1942, p. 508-509; Nickelsen and Hough, 1967, P. 623, 627).

Ver Steeg (1942, p. 509) believes that "the jointing in the coal beds of Ohio is the result of the same tectonic forces which produced the folded Appalachians." Nickelsen and Hough (1967, p. 626) agree that this indicates "the presence of Appalachian lateral pressure far west of the limit of Appalachian folding," and that tectonic forces do carry impact into eastern Ohio, at least enough to joint coals systematically.

In contrast to his systematically jointed coals, the joints in shale and sandstone on Ver Steeg's 1944 structure map for Ohio (Fig. 5) appear disoriented and confused, revealing no regional systematic trend. Nickelsen and Hough agree, stating that few systematically oriented joints in shale and sandstone exist in eastern Ohio because the distance from the Appalachian stress center reduces jointing frequency and decreases consistent joint orientation.

It is true that systematic joints in shale and sandstone do not exist in eastern Ohio, but this does not eliminate the likelihood of regionally oriented nonsystematic joints, a possibility that Ver Steeg and Nickelsen and Hough apparently overlooked, since they concluded that the nonsystematic joints were haphazard in orientation without a detailed study in eastern Ohio. The evidence of concentrated systematic coal jointing in eastern Ohio and especially eastern Hocking County, as shown by Ver Steeg to relate to Appalachian axial folds, is an indication

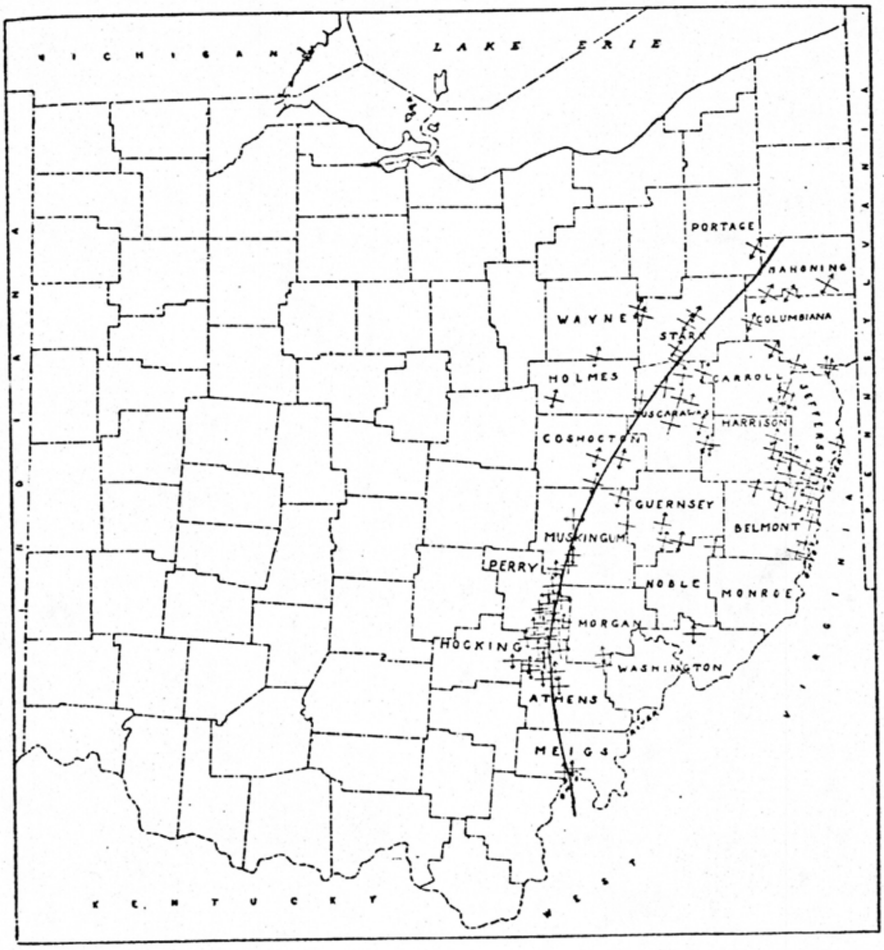


Figure 4. Taken from Economic Geology, 1942, p. 507. Ver Steeg's 1942 map showing orientation of joints in eastern Ohio coal beds. Systematic face joints indicated by straight lines; nonsystematic butt joints by barbed lines. Apparently Ver Steeg's interpretation of face and butt cleats is reversed from the definitions used by Nickelsen and Hough,(1967, p. 623).

The black curve drawn perpendicular to the systematic face cleats parallels the trend of the Appalachian fold axes in the same latitude in Pennsylvania. Ver Steeg (1942, p. 508-509) interpreted this to indicate "that the jointing in the coal beds of Ohio is the result of the same tectonic forces which produced the folded Appalachians".

of strong directed regional stress in this area.

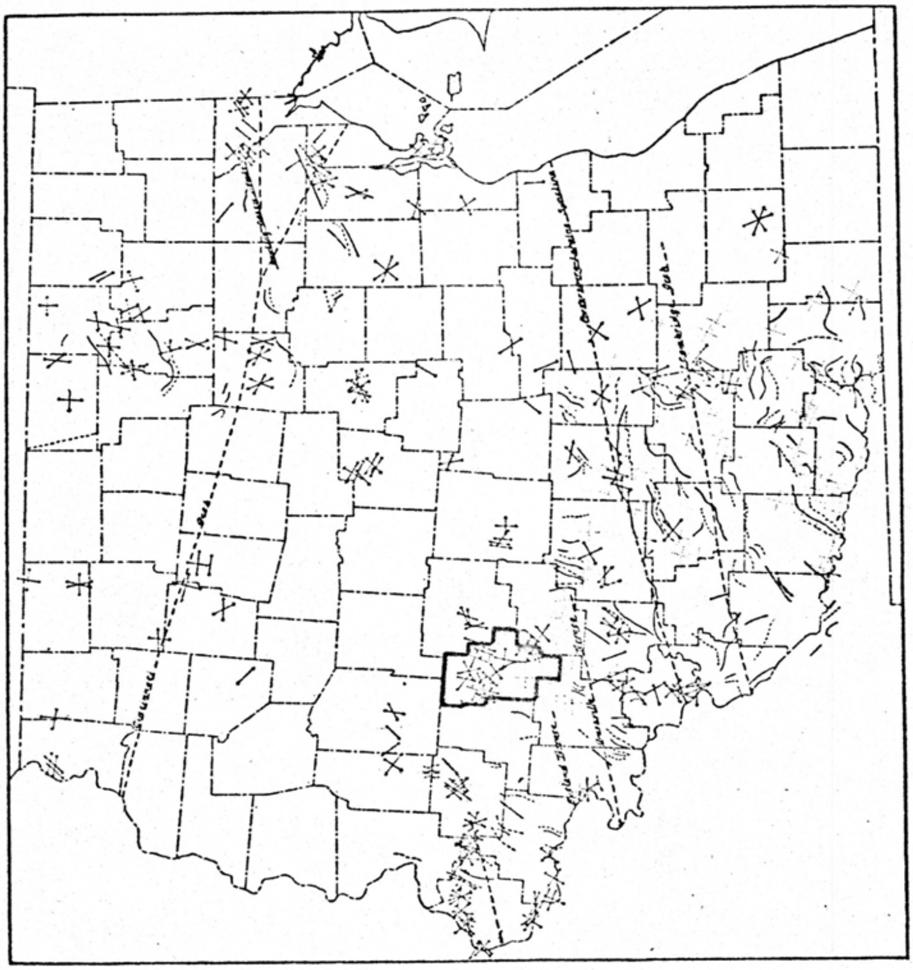
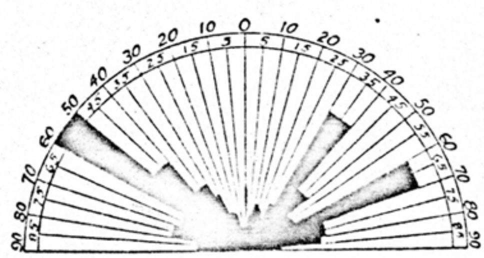


Figure 5. Taken from Journal of Geology, 1944, p. 133. Ver Steeg's 1944 regional structure map of Ohio. Joints for rock formations indicated by solid straight lines tipped by barbs and for coal beds by straight light dotted lines. Hocking County outlined in black.



Ver Steeg's accompanying rose diagram showing joint orientations for Ohio.

Subordinate nonsystematic joints are the perpendicular extensions of systematic joints and form as residual release structures dependent upon their corresponding systematic joint sets. Because of this relationship, nonsystematic joints are just as useful as systematic joints in determining regional orientation when systematic jointing is not developed, as in eastern Ohio, because of a dying out of initial compressive forces. Major reasons for overlooking nonsystematic joints as regional structure indicators is that stress fields are of a low order of magnitude and do not display easily recognizable characteristic jointing traits. Nonsystematic joints do not continue across other intersect joint sets, and since they are not exposed until weathered, they are poorly developed in size and extent (Hodgson, 1961a, p. 25-26).

According to Price (1959, p. 150, 166-167), nonsystematic joints are post-tectonic in origin and develop because of lateral expansion and tensile stress as a result of uplift, with orientation determined by residual stresses. Nickelsen and Hough (1967, p. 624, 627) agree that it is not clear whether jointing only at the surface could be a systematic part of the total joint pattern originally developed in the rock or nonsystematic jointing resulting in some way from residual principal stresses reoriented and made operative during uplift and unloading. The fact that nonsystematic joints are perpendicular to systematic joints indicates that a residual tectonic principal stress as well as the local variable stress, related to topography and unloading, are important in their formation. Therefore, the jointing patterns in the Hocking Hills State Parks can be related to Appalachian systematic joint sets if the trend in Hocking County is of regional significance and parallels the systematic Appalachian joint set orientations.

JOINTING IN THE HOCKING HILLS STATE PARKS REGION

Jointing types are separated into major systematic and nonsystematic jointing, which develop regional patterns, and minor topographically controlled jointing. Minor joints are relatively small, local fractures that develop because of expansion due to weathering of already exposed surfaces (Chapman, 1958, p. 552-553), exhibited mostly as exfoliation and sheeting. They do not express any significant orientation patterns in the Hocking region, except in direct relationship with patterned nonsystematic joints. They will be discussed in relation to their influence upon topography later in this paper.

Since dominant systematic joint sets apparently do not exist in eastern Ohio, the only type of major jointing is the nonsystematic joint set. In the Hocking Hills Park region, nonsystematic jointing displays similar techniques in controlling topographic development in most locations, although jointing patterns vary for each Park (see data sheet, Fig. 7) because the changing lithology of the Black Hand sandstone prohibits identical joint expression everywhere.

Nonsystematic joints are determined by their extent, apparent size, and possible structural and geomorphological significance. Most joints in the cliff walls of the Black Hand sandstone gorges, the only outcrops with extensive joint exposures, are vertical in orientation, either perpendicular to the valley wall or parallel and following the trends of accompanying streams. Their spacing is measured in feet, with varying frequency depending upon the age of exposure. Joints have a small extent into the outcrop and taper out with depth, being confined to the upper fifty to one hundred feet of Black Hand, unless influenced by a stream tributary. It is a significantly frequent occurrence for streams to flow along joints, weathering them at a greater rate than the surrounding rock and developing a permanent watercourse that cuts deep, rapidly removing evidence of the weathered joint, except at the slope break. Joint frequency also decreases with depth into the hollow, as less time for exposure allows for the development of fewer joints.

The nonsystematic release joints in the Hocking Hills State Parks consist of two dominant, perpendicular intersecting sets identical to the fundamental joint system, except distant enough from the initial compressive Appalachian force that neither set systematically intersects and truncates the other. There is some apparent cross cutting of joints, but it is not extensive or well exposed to permit accurate determination of a possible systematic joint set.

This lack of a dominant joint set does not eliminate the possibility of a regional trend, however. Recent fieldwork with oriented cores by gas and oil companies has show that the preferred direction of fracturing in Hocking County is N.63°E., with a majority of the jointing between N. 55°-75°E. This correlates with their surface joint sets and orientation of principal horizontal compressive stress measurements for Hocking County (Overbey and Henniger, 1971, p. 200). This preliminary indication establishes that nonsystematic joints in Hocking County have a regional trend.

It is now necessary to discover the complete regional pattern of jointing and relate this to the Appalachian structural orientations determined by Nickelsen and Hough. If comparable, these regionally oriented nonsystematic release joints are the direct westward extensions of Appalachian systematic joint sets, and are formed by late release of residual stresses tectonically related to previous Appalachian folding.

RESULTS OF FIELDWORK

Fieldwork results show the basic joint pattern breaks the Black Hand sandstone into large rectangular blocks by widely spaced joints of at least two patterned joint systems intersecting at approximately right angles. Compiling all the joint bearing data on a rose diagram (Fig. 6) reveals significant prominent jointing trends for the Hocking Hills State Parks region.

The two most prominent trends are oriented between N.70°-80°E. and N.70°-80°W. These results are almost identical to the N.68°E. and N.84°W. systematic joint trends reported by Nickelsen and Hough (Fig. 3) for the same latitude in southern Pennsylvania, especially considering that the non-systematic jointing in Hocking County is not as precise as those toward the east because of the distance from the structural center of Appalachian jointing. Comparing Nickelsen and Hough's structural map, Hocking jointing results, and curving Appalachian trend, it might appear that the Hocking area could be at the intersection of two overlapping fundamental joint sets. Evidence for this was not found. The reasons were several: a lack of well expressed precise joint frequencies because of the distance from stress centers, lack of systematic jointing, inability of the varying Black Hand sandstone lithology to reproduce definite joint patterns throughout the area, and the small size of the study area.

If there is no attempt to differentiate the two prominent east-west joint sets, then the prominent north-south trending joints most likely comprise the complementary nonsystematic cross joint set striking perpendicular to the regionally oriented east-west trend.

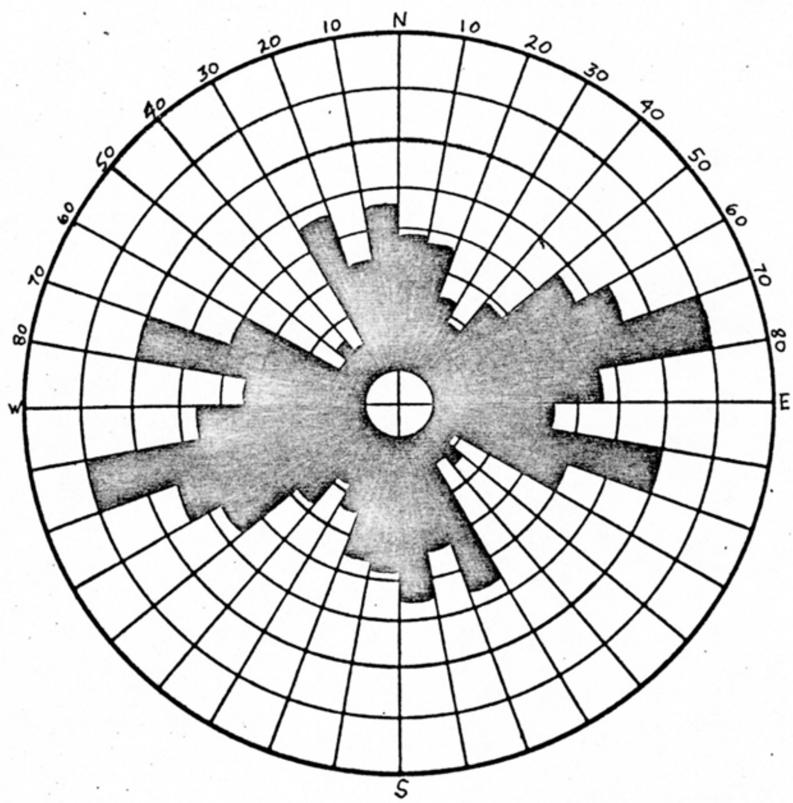


Figure 6. Rose Diagram showing orientation of 325 joints in the Hocking Hills State Parks area. One unit equivalent to five joints.

FIGURE 7

Data Sheet for 325 joints, showing orientation and frequency in each Hocking Hills State Park

Bearing	Cantwell Cliffs	Rock House S.R. 374	Conkles Hollow	Crain,Long Hollows	Old Man's Cave	Cedar Falls	Ash Cave	Total
N86-90W	1			3				4
N81-85W	2		2	5	2	1	1	13
N76-80W	4	1	2	5	2	2		16
N71-75W	5		3	6				14
N66-70W	5			1	5	1		12
N61-65W	2		1	2	2		1	8
N56-60W	1			1				2
N51-55W	1			1				2
N46-50W		3			1			4
N41-45W		3						3
N36-40W	1	1						2
N31-35W		1			1		1	3
N26-30W	1	2	1	1		1		6
N21-25W	4	2	3	3	3	2		17
N16-20W	1	1	1		2	2		7
N11-15W	5	1	1			1	1	9
N06-10W	6			1		3	2	12
N01-05W	8	2			1			11
N00-05E	5			1	2		1	9
N06-10E	2		2	2	3	1		10
N11-15E	1		1			1	1	4
N16-20E	1		5	5	3			14
N21-25E	2			2	2		1	7
N26-30E	1	2	1	1				5
N31-35E		1	2			1		4
N36-40E		1	1	2			1	5
N41-45E			2		1	2	1	6
N46-50E	1	1	2	2	1	1		8
N51-55E	1		2	1	2	2	4	12
N56-60E	2		3	2	2		2	11
N61-65E	2	1	2		3	1	2	11
N66-70E	1	5	5	2	3			16
N71-75E		2	3	2	4	1		12
N76-80E	1		6	1	8	5	2	23
N81-85E	3	1	2	1	5	4	1	17
N86-90E			2		2	2		6
Total	70	31	55	53	60	34	22	325

Comparing these results with Ver Steeg's coal joint map (Fig. 4) indicates similar north-south, east-west joint trends since the overprinted systematic coal joints have been reoriented by systematic joint patterns from western Pennsylvania (Nickelsen and Hough, 1967, p. 623). Ver Steeg's rose diagram for joint orientations throughout Ohio is vaguely similar, but his haphazard orientation for nonsystematic jointing in Hocking County is inaccurate (Fig. 5). These field results have indicated that jointing in this region, although nonsystematic, is regionally oriented similar to the systematic joint patterns of coals in eastern Ohio and the systematic joints in shales and sandstones in Pennsylvania.

If the jointing in the Hocking Hills State Parks is related to structure in the east, then its origin must be related to the forces that caused the systematic jointing along the Appalachian fold axes. According to Chapman (1958, p. 552, 556), the decrease in joint frequency with depth and the association of abundant joints with specific topographic forms supports the belief that most nonsystematic joints are expressions of superficial origin due to the removal of overburden. This is consistent with Nickelsen and Hough (1967, p. 626-627), who state that nonsystematic joints are late release fractures formed during uplift. These simple extension and release joints in the Hocking Hills State Parks were caused by the release of Permian horizontal compressive stress and subsequent uplift of the region in the Mesozoic and Pleistocene. The appearance of jointing in shale, sandstone, and coal did not occur until the removal of overlying Pennsylvanian rock units during the Pleistocene, exposing the Black Hand sandstone to weathering.

Because of the regional orientation of nonsystematic joints in the Hocking Hills State Parks, it is concluded that these residual stress release fractures result from the same tectonic forces that created the systematic joint sets and the Appalachian axial folds in Pennsylvania, and are the western extensions of the systematic jointing patterns found there.

CHAPTER 2

PHYSIOGRAPHY OF THE HOCKING HILLS STATE PARKS

The physiography of Hocking County is characteristic of the unglaciated, maturely dissected, upland portion of the Appalachian Plateau; but the special combination of glacially altered stream drainage and differentially weathered Black Hand sandstone, both controlled by jointing, has resulted in the development of the unusual scenic features exposed in the Hocking Hills State Parks. The topography is separated into two distinct physiographies, representing old and new erosion cycles, by the resistent upper unit of the Black Hand sandstone. The broad shallow valleys and rounded hills of the upland, composed of fine-grained shales and sandstones of the late Mississipian Logan Formation, represents the Tertiary Lexington-Worthington erosion surface as evidenced by rounded hilltops throughout the area averaging 1050 feet in elevation (Stout and Lamb, 1938, p. 57-58; Ver Steeg, 1933, p. 22).

Since the inititation of the latest uplift and erosion cycle during the Pleistocene (Hall, 1971 repr., p. 20), which caused the development of jointing fractures, youthful streams in the gorges have been actively cutting headward, causing an abrupt slope break at the resistant upper unit of the Black Hand. Many of the swift flowing intermittent streams have formed narrow valleys with 150 foot steep-walled cliffs, semicircular overhanging precipices with 30 to 100 foot high waterfalls, and large reentrant caves. The expression of most of these features is due to the differential weathering of the Black Hand sandstone, exposed during the Pleistocene due to climatic changes brought about by the close association with Illinoian and Wisconsin glaciations. The glacial boundary, five miles northwest of the Park region, caused increased precipitation and stream discharge which permitted rapid erosion and downcutting through the Black Hand.

LITHOLOGY OF THE BLACK HAND SANDSTONE

The Black Hand member of the late Mississipian Cuyahoga Formation is a deltaic sandstone facies (Ver Steeg, 1933, p. 25; Hall, 1951, p. 39) locally time equivalent to the underlying Cuyahoga shale member and extending over 100 miles north to south and several hundred miles to the east (Hall, 1971 repr., p. 17-18). It is the major lithologic unit responsible for forming the scenic prominent ledges, steep-sided gorges, vertical-walled cliffs, and reentrant caves, due to the differentially weatherable three-part lithology of the Black Hand sandstone. The most spectacular of these features, which have been set aside as State Parks, also contains the best expressed jointing. Development of these jointing sets by weathering of the Black Hand is responsible for forming the present Park topography.

The Black Hand is dominantly a gritty, friable, reddish brown to buff colored, medium to coarse-grained, well-sorted sandstone of almost pure quartz containing rounded white quartz pebbles 1/16 to 1/2 inch in diameter scattered throughout and concentrated in conglomeratic lenses. The member is primarily non-fossiliferous and cross-bedded with a gentle two-to-four degree northward dip, indicating a source area to the southeast. It has a variable thickness of 95-175 feet in Benton Township because of the facies relationship. The regional strike is slightly east of north, and the regional dip is 30 feet per mile southeastward (Hall, 1951, p. 32-40; 1971 repr., p. 19).

The massive upper unit, 15 to 40 feet thick, is consistent throughout the Park area. It contains many coarse conglomerate quartz lenses near the surface of the unit, firmly cemented with silica and iron oxide cement making it extremely resistant to weathering. This upper unit forms the caprock rims under which the Park features are eroded.

The middle unit is the most variable. It may consist of cross-bedded, loosely cemented, friable sandstone with banded iron concentrations, or irregular long sweeping cross-beds of fine-grained sandstone and clay-shale. Its softness permits differential weathering, honeycomb structure, and rib and cavernous weathering, such as the pronounced recess shelter caves at Old Man's Cave and Ash Cave. However, when the middle unit is lithologically similar to the upper Black Hand unit, as at Conkles Hollow, the difference is difficult to distinguish and cliff faces may reach 250 feet of vertical sandstone and conglomerate.

The lower unit of the Black Hand is much like the upper unit. It is well-sorted, fine to medium-grained, firmly cemented, horizontally bedded sandstone with fewer pebble conglomerates. Near its base it grades into thin-bedded sandstones with sandy shale and clay interbeds which form the bottom unit of exposures in the lower stream valleys throughout much of the Park region.

TOPOGRAPHIC RELATIONS TO JOINTING

Water is the principle weathering agent of both major and minor jointing in the Black Hand sandstone. Minor jointing consists of rock fractures that have formed because of weathering of previously exposed rock, primarily expressed as exfoliation and sheeting joints that develop in the ceilings and walls of the reentrant caves and amphitheaters. These joints may work in association with major jointing to shape the rock, or may be solely responsible for rock removal. Water filtering through joint fractures emerges at stream level along porus bedding planes, forming reentrants by basal sapping. Many streams also flow along weathered joints before falling into the plunge pools of the recessed semicircular amphitheaters below. The spray from the waterfall has a sapping effect on the friable middle unit of Black Hand sandstone. After sapping, expansion of the rock due to the release of stress on the freshly exposed reentrant develops exfoliation fractures paralleling the concave surface. Generally the whole interior wall and ceiling of the recess will be shaped by exfoliation fracturing along the same surface. Blocks near the base of the waterfall that are separated from the walls by the concave planar surface of the exfoliation dome weather by sheeting along bedding planes.

Weathering by water of the nonsystematic major joint sets along the valley walls is the primary method of valley widening, accomplished by rock fall. The cliff walls of many hollows form along release joints parallel to the initial joint containing the stream and are intersected at 90 degrees by cross joints perpendicular to the cliff face. Filtering water weathers these joints, separating the rock into large rectangular blocks that may fall or slump away from the valley wall along joints that follow the trend of the joint-controlled stream valley. That there is a "tendency for the smaller streams to follow the larger joints, which offer less resistance to erosion" was observed by Ver Steeg (1933, p. 28). Apparently there is a direct relationship among topographic features, stream drainage, and jointing patterns in the Hocking Hills State Parks that can be explained by a summary of the dominant jointing relations in each Park area.

CONKLES HOLLOW

Located three miles northwest of Old Man's Cave on State Route 374, Conkles Hollow is the most central of the Hocking Hills State Parks. The hollow, a straight half-mile deep valley, is one of the younger valleys in the area still experiencing rapid erosion. The lithologic similarity of the middle Black Hand to its upper unit forms cliff faces 200-250 feet, the highest in the Parks. These massive cliff walls, combined with the simple structure of the hollow permit analysis of the jointing patterns and their influence upon topography without much difficulty. Interpretation of the developmental characteristics of this young valley, applied to the older, more

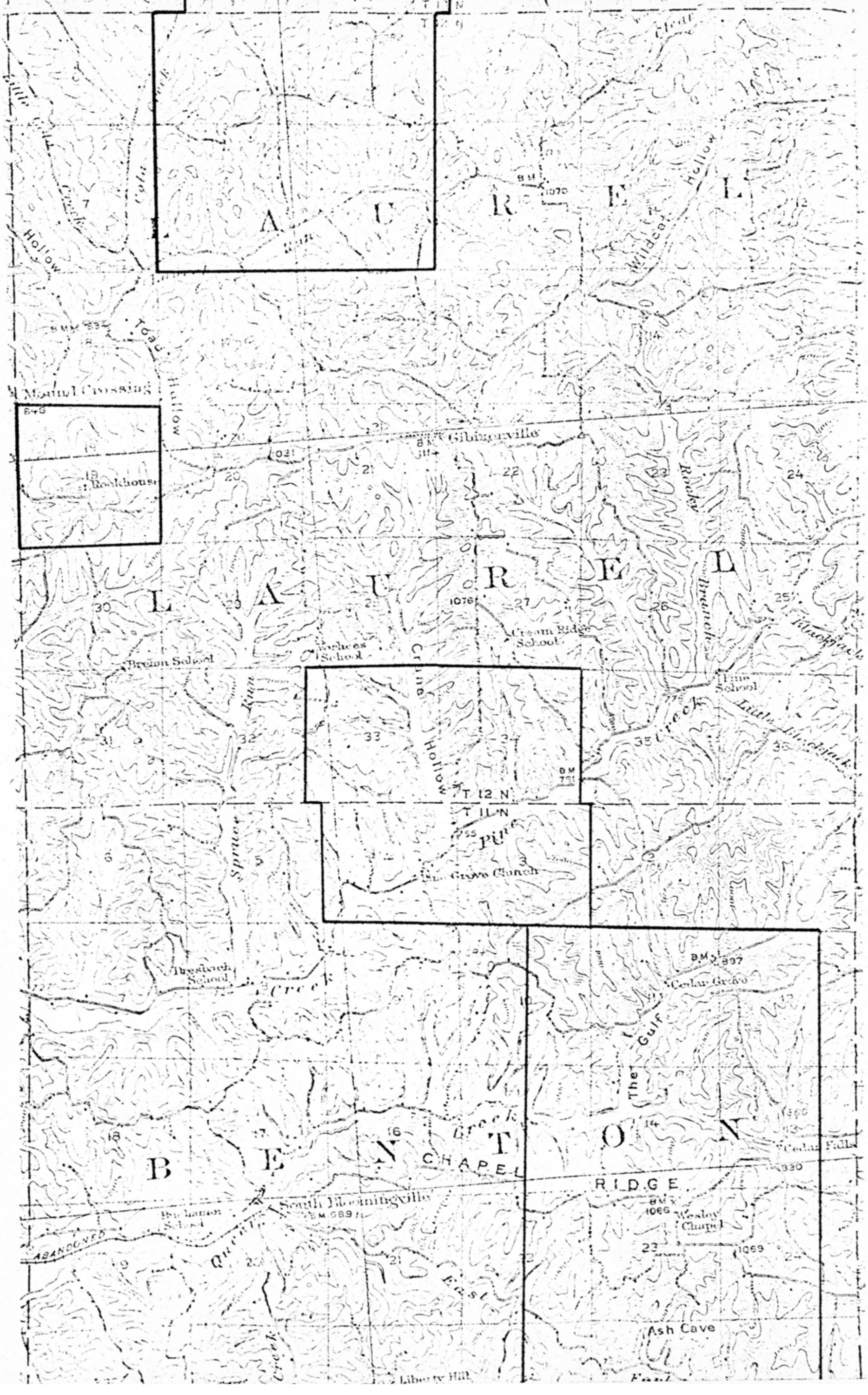


Figure 8. Map of Benton and Laurel Townships showing State Park areas where jointing patterns were recorded.

complexly joint-weathered locations permits determination of the jointing patterns and related physiographic developments in these surrounding Park areas.

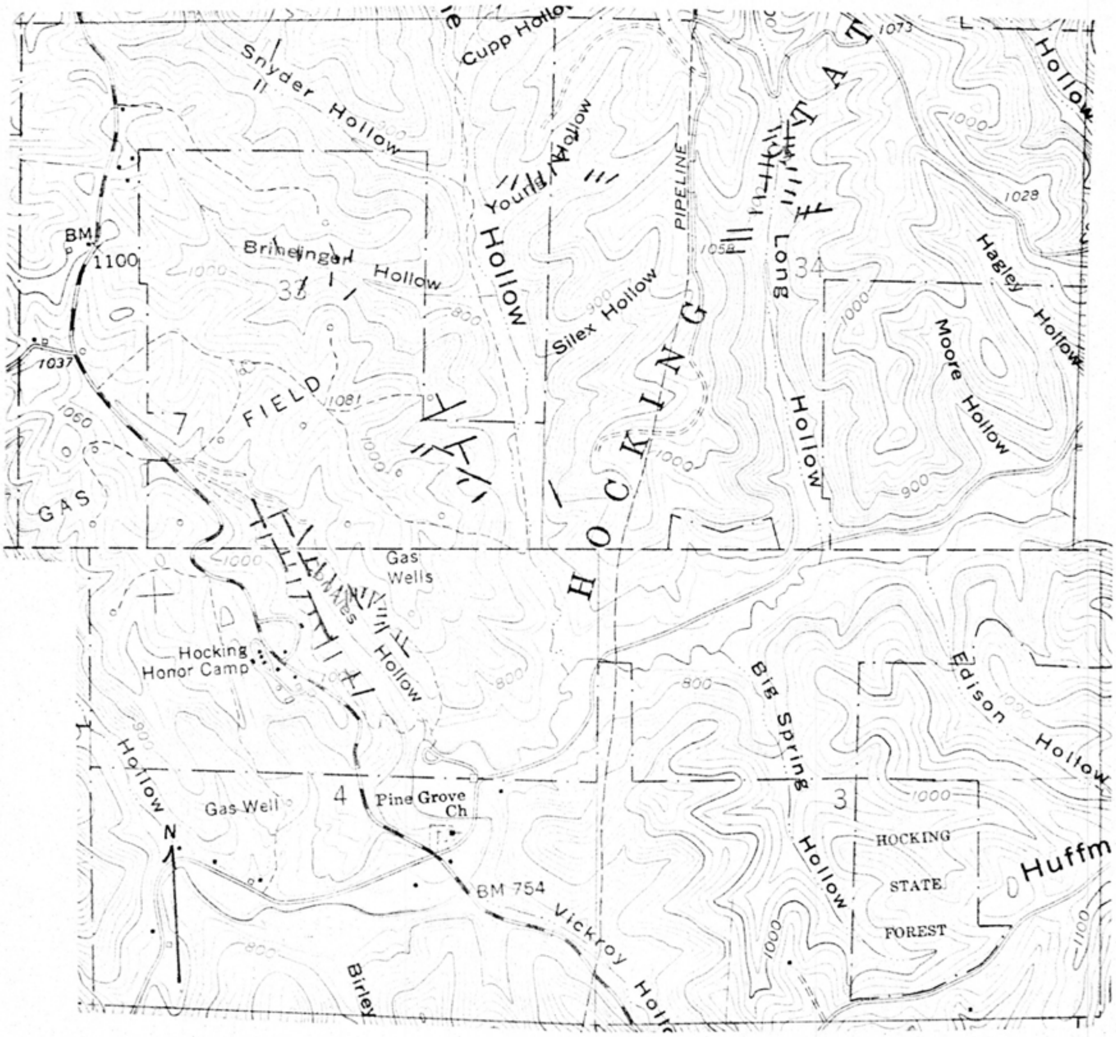


Figure 9. Orientation of jointing at Conkles, Crane, and Long Hollows to show major trends and patterns. Not all joints indicated. Length of lines indicate relative size and extent of jointing. South Bloomingville Quadrangle, 1961.

Although Conkles Hollow is comparatively younger than other Parks, its valley development is topographically characteristic of all deep-valleys in the region. Frequency of jointing, which is directly related to the duration of exposure, decreases with depth into the gorge until only the initial characteristic jointing pattern is revealed. At the head of Conkles Hollow, the valley walls rise over 200 feet, closing in on the narrow stream. The waterfall, falling over three distinct step-levels which correspond to the three units of the Black Hand, flows down a major joint bearing N.23°W. The only other joint in this area is a well developed N.67°E. joint, intersecting at right angles. That this is the major jointing pattern is further proven by the valley trend of N.20°W. It is formed by parallel sets of joints along the valley walls which have separated large blocks of sandstone that fill the stream floor.

In the middle region of the hollow the valley walls widen due to more joint-controlled rockfalls, as jointing frequency increases rapidly. Besides the joints paralleling the stream valley, numerous cross joints are prominently oriented perpendicular to the valley walls. Not all the joints are equally exposed, since differential weathering and side tributary runoff have a significant effect on their development; but some of the joints are traceable across the valley floor to the opposite wall, and many are responsible for causing the rockfall debris. The largest, most recent rockfall, located one-third the distance into the hollow along the east wall, is revealed by its buff colored cliff face, which has not been exposed long enough to undergo casehardening to the characteristic gray color of the weathered Black Hand sandstone.

The mouth of the hollow has the appearance of a mature deep-valley topography. The high walls are far removed from the valley floor and the fallen weathered blocks are covered with thin soil, leaf litter, and dense vegetation making it difficult to observe the jointing which exists only in the remaining uncovered small exposure of the upper Black Hand.

East of Conkles Hollow, Crane Hollow is also characteristic of the mature deep-valley stage, except at the heads of narrow side streams where it resembles the inner depths of Conkles

Hollow. To the east the jointing in Long Hollow is best expressed deep in the hollow where weathering along perpendicular intersecting joints have developed an enclosed cave recessed 45 feet with an opening 30 feet high. Jointing patterns for these areas are similar to that found in Conkles Hollow.

OLD MAN'S CAVE

Old Man's Cave State Park, located on State Route 664, is the best known of the Hocking Hills State Parks. The Park extends a half-mile southwestward along a small stream before turning south for three-fourths of a mile in a region known as The Gulf. Here the stream joins with westward flowing Queer Creek, the eastward extension of which terminates at Cedar Falls.

Unlike Conkles Hollow's three step-level waterfall, the stream at Old Man's Cave has eroded the Black Hand sandstone units at different rates, thus creating a separate Upper Falls at the top of the upper Black Hand, and a Lower Falls at the top of the lower Black Hand, a half-mile west.

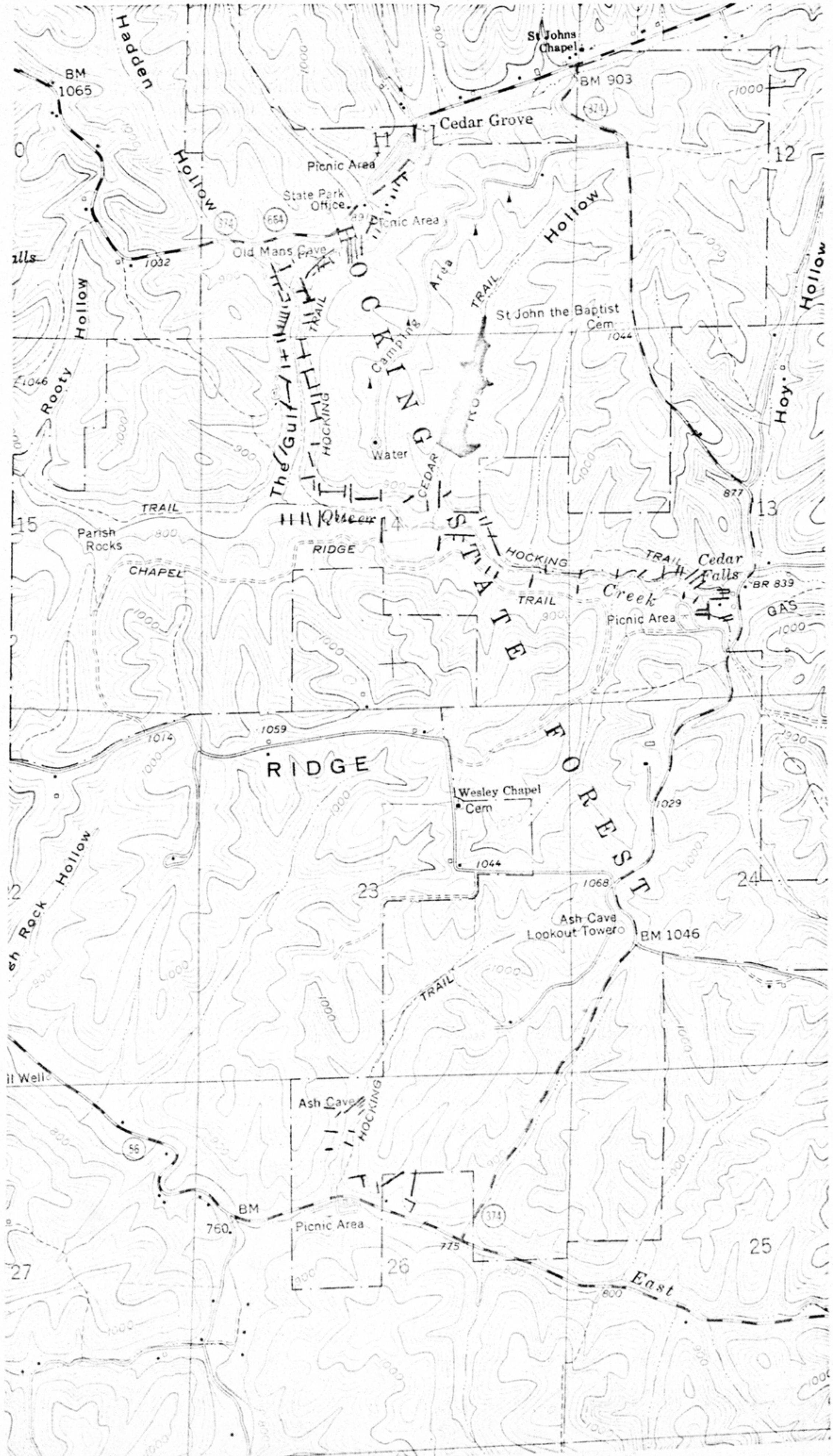


Figure 10. Orientation of jointing in Old Man's Cave, Cedar Falls, and Ash Cave State Parks to show major trends and patterns. Not all joints indicated. Length of lines indicate relative size and extent of jointing. South Bloomingville Quadrangle, 1961.

The upper valley at Old Man's Cave is shallow for over a quarter-mile, displaying the characteristic development of a shallow young valley. The Upper Falls drops 25 feet before beginning the half-mile run through the middle Black Hand sandstone gorge to the Lower Falls. Few joints are exposed at the head of this upper region and the waterfall flows over intact upper Black Hand conglomerate. Further west, the upper valley walls are straight, but wide angle offsets indicate that the stream apparently follows intersecting jointing sets trending N.50°E. and offset by cross jointing. Valley widening in this section is accomplished by intersecting joints of large angle, not necessarily right angles, separating angular blocks from the short valley walls. Several large rockfall blocks are west of a small joint controlled tributary at the southwest end of the parking area. The joints separating these blocks from the cliff wall have no preferred joint orientation although N.70°W. and N.85°W. joints, with north-south trending cross joints, are exposed in the remaining angular walls. Apparently this random wide angle jointing, observed throughout the Park region, is the pattern of early shallow-valley widening.

Moving deeper through the middle Black Hand above Old Man's Cave, jointing trends east-west along the valley walls, intersected by north-south perpendicular cross joints. Old Man's Cave proper, a recess cave in the middle Black Hand, is 200 feet long, 50 feet high at the overhang, and 75 feet in depth from the overhanging ledge of upper Black Hand sandstone. Jointing has had little influence in forming this popular attraction, as

Figure 11. Example of a joint parallel to the cliff face separating a large block above the Lower Falls at Old Man's Cave. Notice that the joint extends 40 feet to the bottom of the picture. Rockfall caused by weathering along these joints is responsible for valley widening.

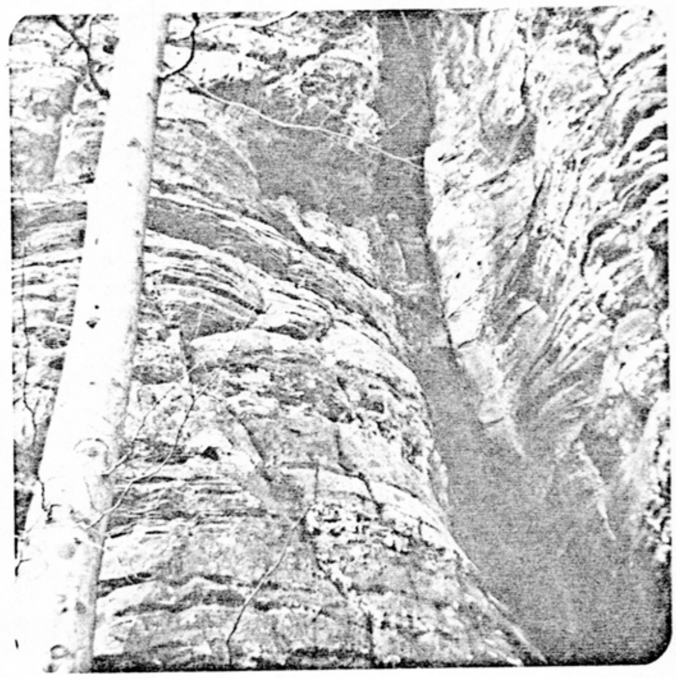


Figure 12. Water running down a joint fracture has weathered it more rapidly than the surrounding rock. This same principle permits streams to rapidly cut into the Black Hand sandstone following jointing. Picture taken in the Gulf region. Tree is for scale.

only one joint, trending N.70°W., cuts the ceiling of the recess without much effect.

West of Old Man's Cave, the north face of the valley wall trends N.75°E., terminating against a protruding rock slab that has not been exfoliated. Just above the Lower Falls another joint trends N.80°W. along the north wall, replacing the first joint and separating a large section of the wall into the stream valley. Crossing the stream, the south face of the valley trends N.55°E. along jointing that forms almost 300 feet of smooth, vertical exposure past the Lower Falls. This apparently is the dominant trend along the valley walls west of Old Man's Cave.

The Lower Falls is supported by the top of the lower Black Hand sandstone unit, falling about 40 feet into a plunge pool located in the underlying Cuyahoga shale. This unit is also exposed at the base of the large recess cave on the southwest side of the falls. The reentrant, because of its association with the waterfall and plunge pool, is weathering more rapidly than Old Man's Cave, which is exposed to the sun. Waterfall sapping and basal sapping along the Black Hand sandstone-Cuyahoga shale contact accounts for most of the weathering in this recess. The floor is covered with sand and fallen blocks, while the ceiling reveals several developing convex exfoliation fractures.

A short distance past the Lower Falls the stream abruptly turns southward, with the addition of a tributary from Broken Rock Gorge. The short valley of this small stream is choked with huge boulders and the stream waterfall flows through a joint fracture bearing N.20°W. Joints parallel to this in the valley walls, along with their perpendicular cross joints, have caused these huge rockfalls. At the intersection of these two streams, the one from Old Man's Cave is trending about N.70°E. as revealed by jointing in the cliff wall behind the junction. The stream from Broken Rock Falls is controlled by jointing bearing N.20°W. This right angle intersection provides further indication that the stream flowing through Old Man's Cave is joint controlled.

The Gulf is a well developed valley with upper and middle Black Hand sandstone walls 140 feet above stream level trending along parallel joints bearing N.20°W. Sizable cross joints intersect these faces about every 30-50 feet with bearings between

N.65°-80°E. At several places the cliff wall offsets back to another N.20°W. parallel joint at a break in the wall near a side tributary, follows this new parallel face for a distance, separates a few blocks from the wall, and then becomes indistinct as the original joint face reappears. As the junction between The Gulf and Queer Creek is reached, the valley wall exhibits perpendicular intersection of jointing at the corner and then joints trending N.85°W. begin to dominate the valley wall pattern. This pattern continues to form the valley wall up to Rose Hollow, a half-mile downstream from Cedar Falls.

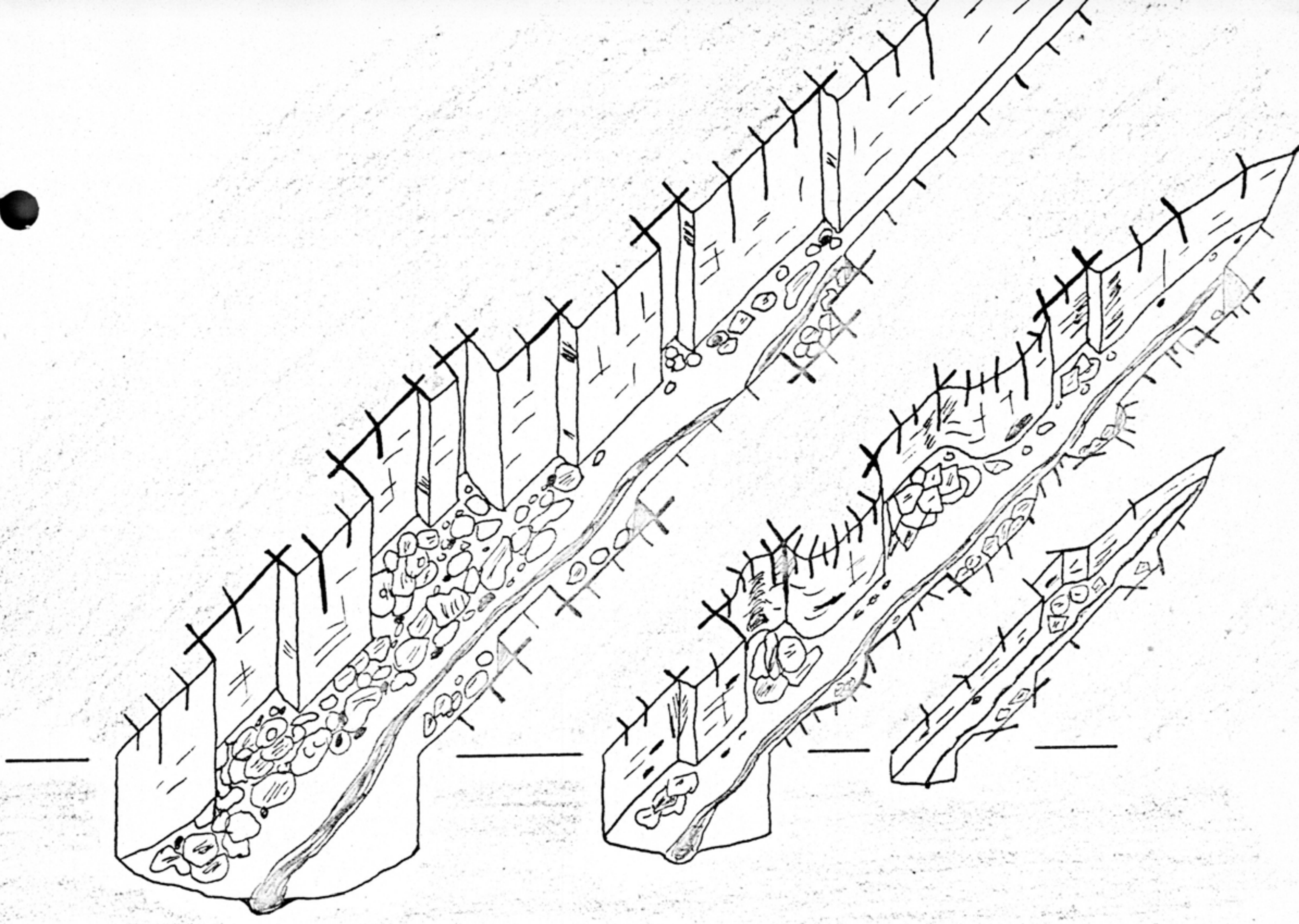
METHODS OF VALLEY DEVELOPMENT BY JOINTING

There are two basic types of valley development based upon jointing in the Hocking Hills State Parks. Examples of these are best displayed by only two Parks, Conkles Hollow and Old Man's Cave, while other special factors have contributed to forming the features of the other Parks. One type of development is characteristic of a continuous deep-valley cutting the Black Hand at two separate localities, forming a giant step in the valley. Below this step, however, both valleys are deeply weathered and develop similarly.

Conkles Hollow is characteristic of deep-valley development controlled by jointing. Deep in the hollow the only evidence of jointing is along regional orientations, with controlled vertical cliff walls and many large rockfall blocks. The upper valley at Old Man's Cave typically displays development by jointing in a shallow-valley. The walls are narrow and intact, except where small stream deviations follow intersecting jointing. Here angular blocks are separated from the wall by the intersecting joints, but jointing frequency elsewhere is undeveloped.

Returning to the deep middle section of Conkles Hollow, jointing frequency has increased rockfall and valley widening along joints that parallel the initial joint at the valley head. Many perpendicular joints intersect the valley walls, fracturing the rock into rectangular blocks.

Below the Lower Falls at Old Man's Cave, the valley has reached a deep-valley stage that is more advanced than Conkles Hollow. The valley walls are 400 feet wide, developing along a third series of joints parallel to the initial stream



Stage C Stage B Stage A

Figure 13. Block diagram of three stages of valley development by jointing. Stage A. Shallow young valley developed along initial joint and widened by high angle intersecting joints separating angular blocks from isolated localities along the valley wall similar to the upper valley at Old Man's Cave. Stage B. Widening of deep-valley along secondary joints parallel to the joint-controlled stream. High frequency of jointing perpendicular to the valley wall results in active widening by rockfall similar to the middle valley at Conkles Hollow. Stage C. Deep-valley walls parallel along well-developed tertiary jointing. Evidence of previous rockfalls plentiful, but present regularly spaced perpendicular side joints responsible for continued widening only at side stream intersections similar to the lower region of The Gulf at Old Man's Cave.
Short straight lines represent jointing; irregular shapes indicate rockfall blocks.

joint. Piling of rockfall blocks from earlier, more frequent fractures has built a gentle slope up to the valley wall, but now that release stresses are more equalized, perpendicularly intersecting joints have consistent orientations and are equally spaced at wider 30-50 foot intervals. The only indication of valley widening is at side stream entrances, where some rockfall is evident and new jointing develops into the rock, parallel to the valley wall. These joints will gradually develop and offset sections of the valley wall, widening it parallel to the initial jointing.

After development reaches this stage, most stresses focused toward the stream have been released and the erosion rate decreases, leaving most of the valley wall covered with rockfall blocks, soil and vegetation almost reaching the rim. This is the situation at the mouth of Conkles Hollow and downstream from The Gulf along Queer Creek.

CEDAR FALLS

East of Rose Hollow, westward flowing Queer Creek is controlled by N.80°W. jointing, except where offset by prominent N.20°W. joints. Approaching Cedar Falls, jointing orientation is primarily perpendicular to the stream, but frequency declines as the height of the valley walls decreases. Cedar Falls (Fig. 10) is a semicircular cliff with a 50-foot high waterfall flowing over the upper and middle Black Hand. A recess, formed by the sapping action of the plunge pool, is filled with blocks, varying from 20 to 1000 cubic feet, that have been differentially weathered along bedding planes and dropped onto the sand and gravel in the basin of the plunge pool.

There are few significant joints at Cedar Falls. Two above the waterfall cut the upper Black Hand in an east-west orientation and one joint 20 feet south trends N.80°E. Topographically Cedar Falls is similar to the Upper Falls area at Old Man's Cave, with few joints developed in the small exposure of Black Hand sandstone.

ASH CAVE

Located two miles south of Cedar Falls along State Route 56, Ash Cave (Fig. 10) is the only significant feature exposed in the Black Hand sandstone throughout the East Fork drainage basin. Along the quarter-mile trail to the spectacular 700 feet long, 90 feet high, and 100 feet depth of recess semicircular reentrant overhang are massive cross-bedded sandstone walls, showing slight differential and honeycomb weathering, but extremely few joints. Ash Cave, appearing as a large weathered reentrant, is actually the result of block removal between parallel northeast trending joints.

The overhang is fractured by two major joints striking N.52°E. (Fig. 14 and 15). The east joint contains the waterfall, while the west joint extends along the northwest face of the upper Black Hand sandstone, 30 feet west of the first. This joint forms the edge of the overhang under which the middle Black Hand is recessed. Few vertical joints penetrate this west side and the distance from the waterfall leaves this section of Ash Cave relatively dry and weathering slowly.

The east half, containing the joint with the waterfall, is usually damp from the moisture of the spray, and sapping of the friable middle Black Hand, causing concave exfoliation of the recess, is proceeding more rapidly than the west half. The upper Black Hand, forming the edge of the overhang, is apparently perpendicular to the N.52°E. joints, but no evidence indicating this face is controlled by jointing was found.

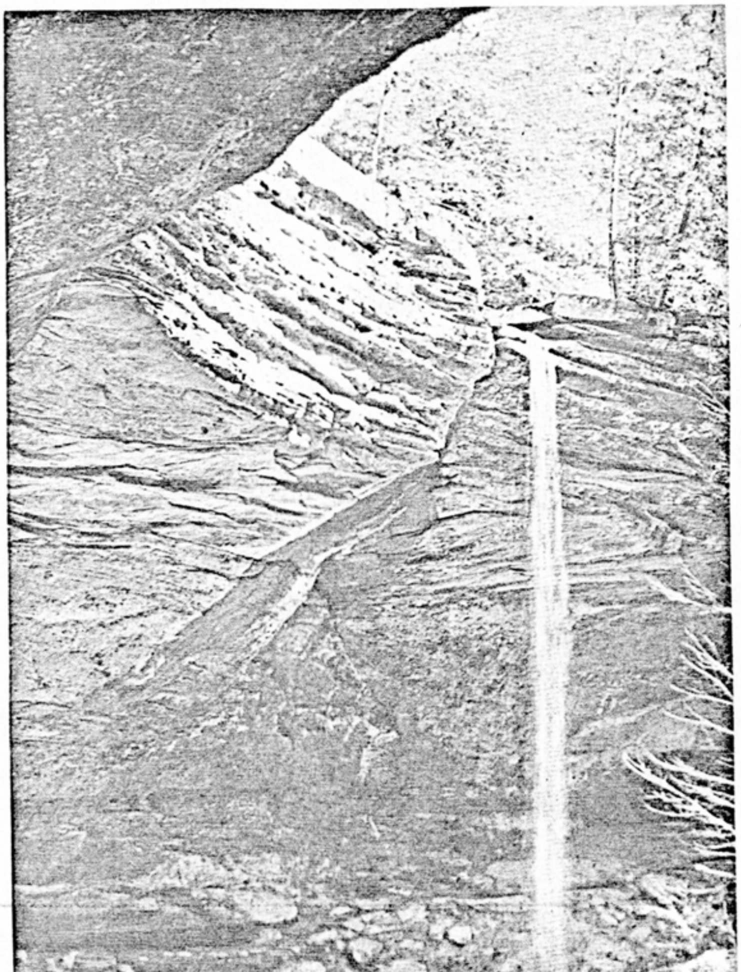


Figure 14. Waterfall flowing along N.52°E. joint at Ash Cave. Note the recess in the middle Black Hand sandstone at the bottom of picture. (Photo taken from DeLong, 1967).

Figure 15. View of parallel jointing at Ash Cave. Joint in background strikes N.52°E. and forms the west face of the recess. Waterfall in the foreground flows through a parallel joint (barely visible). It is along this exposure that Ash Cave is most rapidly weathering.

This writer believes that the apparent perpendicularity of the two upper Black Hand sandstone overhang-forming faces is due to a combination of jointing and blockfall. The east side of the overhang is weathering between the N.52°E. parallel joints, while the west side, except for the area near the intersection of the two faces, is relatively permanent. When the weight of the overhang becomes too great, blocks between the parallel joints break off at right angles to the jointing. The semicircular concave shape of the middle Black Hand around the base of Ash Cave, giving it the appearance of one complete formation, is due to the greater erosion rate of the rock behind the nearby waterfall. This recessing results in rounding the angular differences between the two sides of Ash Cave.

ROCK HOUSE

Five miles northwest of Conkles Hollow, along State Route 374, is the most unusual feature in Ohio, Rock House State Park. Its very existence and location, being the only major exposure in a two square mile area, are due solely to the pattern of jointing and weathering of the Black Hand along cliff face joints. Laurel Run, a small stream at the base of the 100 foot cliff containing Rock House, flows from the base of a 50 foot wide recess, exhibiting the best example of basal sapping in the Hocking Hills State Parks.

Above this stream, Rock House (Fig. 17) is formed along the offset of two parallel joints that trend N.70°E. and dip steeply northwest. The outside joint forms the cliff face and the inside joint runs the 200 foot length of the main corridor. The interior is dissected by five un-equally spaced and differentially weathered cross

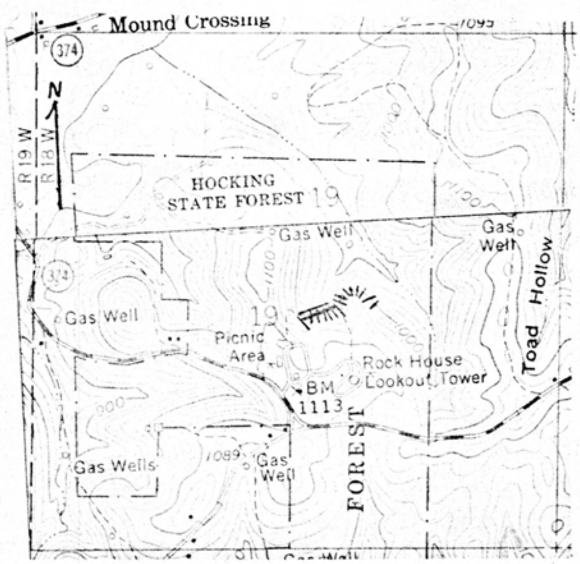


Figure. 16. Orientations of jointing in Rock House State Park to show major trends and patterns. Not all joints indicated. Length of lines indicate relative size and extent of jointing. South Bloomingville and Rockbridge Quadrangles, 1961.

joints (Fig. 18), trending between N.1°W. and N.50°W. They form the Gothic-shaped windows along the northwest exposure. The ends are opened along the master joint by right angle offsets along other cross joints outside Rock House.

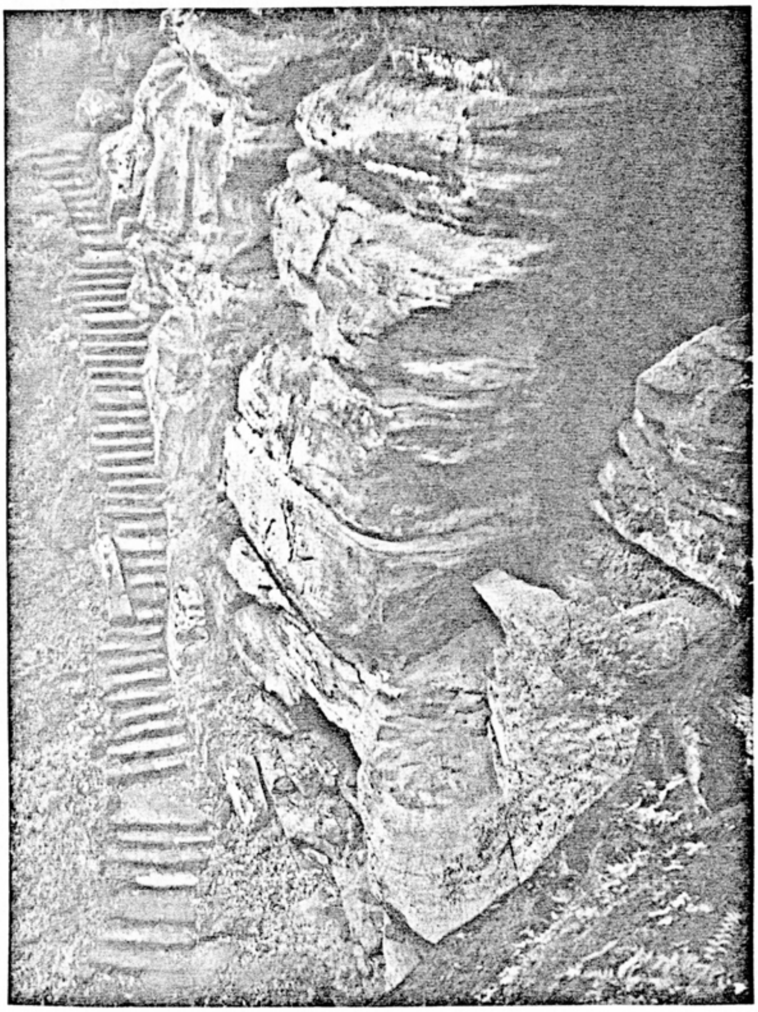


Figure 17. View of Rock House looking southeast. Major N.70°E. joints control the cliff face and run the length of the interior. Cross joints are visible to the right of the steps. (Photo taken from DeLong, 1967)

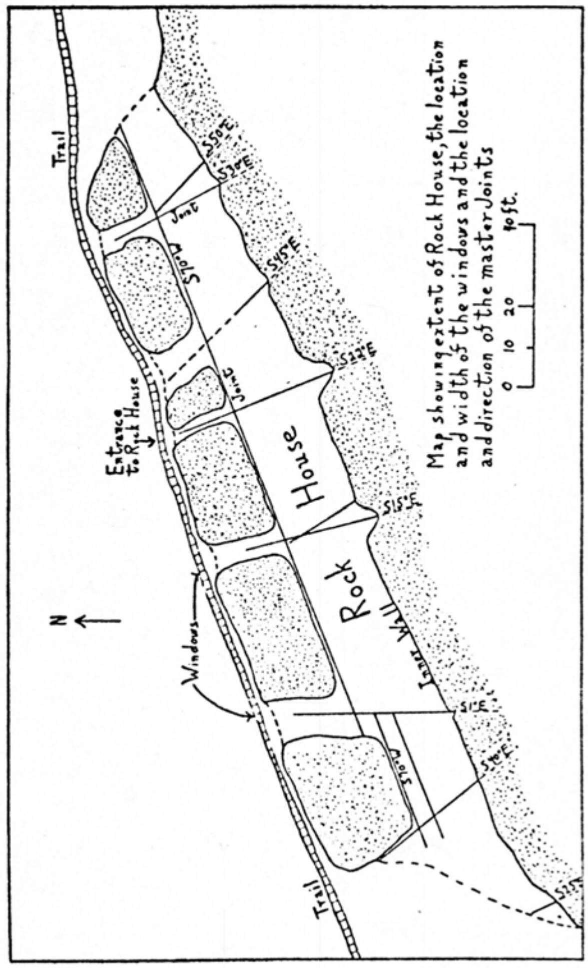


Figure 18. From Carman, Ohio Journal of Science, V. 46, p. 277. Diagram showing orientation of jointing inside Rock House. Offset of the cliff face along joints parallel to the northwest trending cross joints is responsible for exposing Rock House at both open ends.

Inside, the jointing is traceable across the 30 foot high ceiling and back 20 feet to the rear wall. Sapping by water along these joints results in the differentially weathered Gothic-shaped ceiling and windows; and small recesses of several feet formed along these joint traces in the rear wall are due to basal sapping of weak bedding planes.

The master joint bearing N.70°E. along which Rock House is formed does extend west into the cliff wall, but dies out without much exposure. Likewise to the east, the joint disappears behind a topographically fractured nose and its exposure on the other side is indistinct.

CANTWELL CLIFFS

Cantwell Cliffs, located seven miles north of Rock House on State Route 374, is a gigantic semi-circular 100 foot high precipice formed by two intersecting joint sets and the headward erosion of Buck Run. It consists of a large amphitheater recess cave to the west and perpendicular intersecting cliff walls to the east.

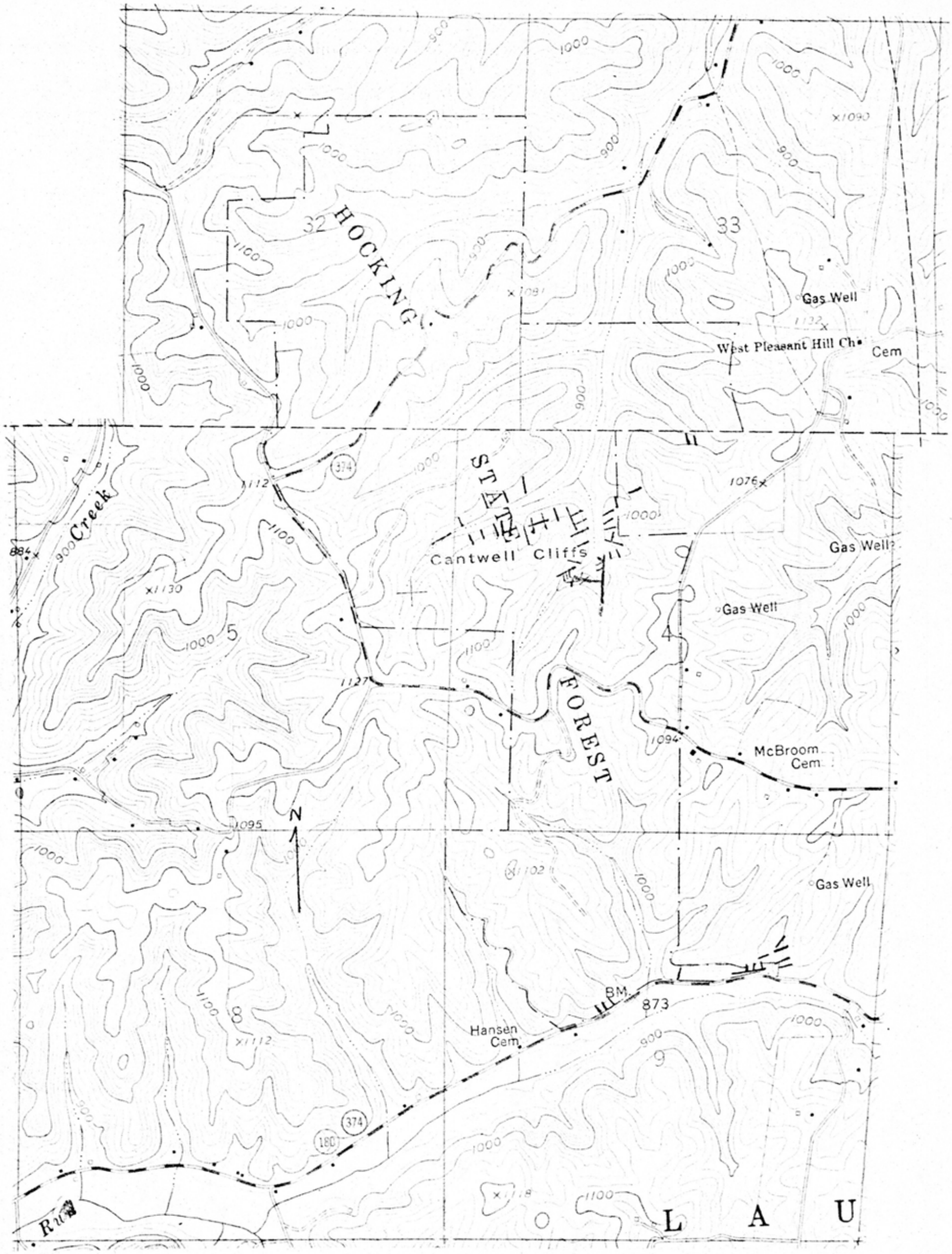


Figure 19. Orientation of jointing in Cantwell Cliffs State Park and along State Route 374 to show major trends and patterns. Not all joints indicated. Length of lines indicate relative size and extent of jointing. Rockbridge Quadrangle, 1961.

The north face of the Cantwell Cliffs precipice is formed by a joint striking N.72°W. Following this joint down its weathered surface through the passageway to the west, (Fig. 20), the space between the cliff wall and the separated joint blocks increases from three to fifteen feet in width as two perpendicular cross joints bearing N.20°E. and N.5°E. intersect the major N.72°W. joint, forming one large joint block and two smaller ones. These blocks have remained in place, and the width of the passageway is evidently due to weathering along these joint surfaces. Thirty feet behind this

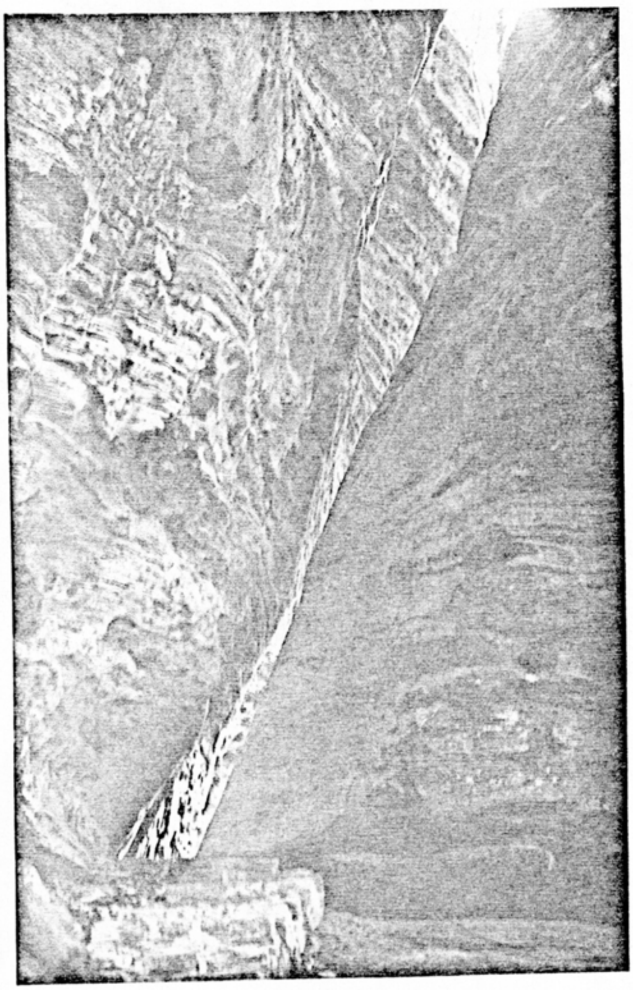


Fig. 20. Weathering along N.70°W. joint at Cantwell Cliffs has formed an opening wide enough to walk through. Joint separated block is on left of picture, view is looking east. (Photo taken from DeLong, 1967).

passageway joint, and exposed along the east edge of the major overhang, is another joint of apparently the same set, but bearing approximately N.85°E. This joint is responsible for forming half of the overhang, since the first major weathered joint does not extend across the amphitheater.

The waterfall flows through a notch in the upper Black Hand, but this joint is not well developed. It might be possible that the joint which forms the west side of the overhang cuts off the westward trend of the other joints, but there is no convincing evidence indicating this.

Few vertical joints are revealed in the overhang, and much of the weathering of this semicircular recess is due to exfoliation and sheeting. The arc of the overhang is fairly constant and the whole reentrant appears to be exfoliated along one concave fracture plane, leaving many slump blocks lying underneath. Along the west wall is a 25 foot long, six foot high section of vertical extension fractures (Fig. 21) formed by the weight of the overlying rock and expansion away from the recess wall. These joints, occurring every four to ten inches and trending approximately N.5°W. are the only series fractures of this type observed in the Parks.

The plunge pool in the lower Black Hand sandstone is 20 feet below the overhang, and basal sapping and sheeting along differentially weak bedding planes has broken loose small

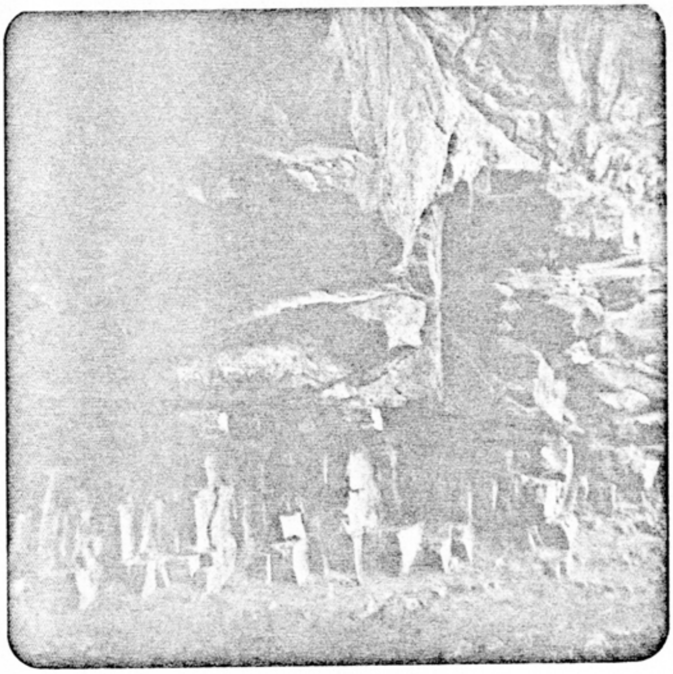


Figure 21. Series of extension fractures under the overhang at Cantwell Cliffs. Exposure is six feet high and 25 feet wide measured perpendicular to the N.5°W. bearing joints. Fracture spacing is between four and ten inches. Clipboard at center of fractures is for scale.

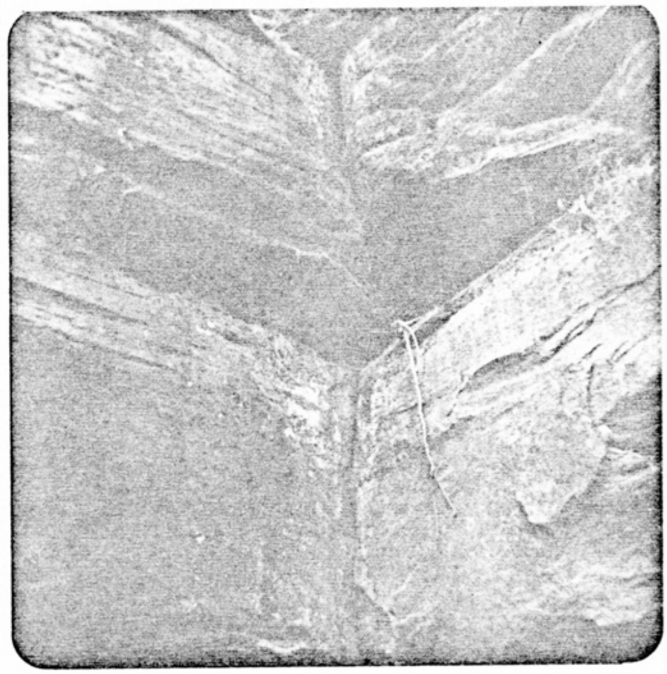


Figure 22. Perpendicular intersection of joint formed cliff walls at Cantwell Cliff Cliff face on the left side of picture is oriented N.5°W. on the right side N.85°E. Apparently the N.5°W. joint cuts off the other face. View is southeast and exposure of cliff face is 30 feet high.

angular pieces and some larger rectangular blocks, partially filling the plunge pool. Jointing down the valley and in the side tributaries extends only through the upper Black Hand and trends perpendicular to the face of the outcrop.

The eastward trace of the N.72°W. precipice joint is replaced by a joint controlled face 50 feet high and trending N.57°W. for a short distance before curving to trend N.85°W. This cliff wall terminates against a similar joint-controlled cliff face trending N.5°E.,making a right angle intersection (Fig. 22). This N.5°E. joint, extending to form the east valley wall probably contains the small stream that runs over the north cliff face near the intersection of the joints.

JOINTING EFFECTS UPON STREAM DRAINAGE

From the Park descriptions it is apparent that jointing influences the development of topographic stream orientations. It is a well-known geologic principle that in areas of regionally oriented systematic jointing, the major stream drainage is controlled by jointing and follows a similar trend.

(Sheldon, 1912, p. 79; Fairbridge, 1968, p. 288, 1078). In the Hocking Hills State Parks region nonsystematic jointing has a regional orientation and therefore should exhibit the same patterned influence on streams that systematic jointing does. It is necessary, therefore, to determine what regional control the apparently regionally oriented nonsystematic jointing patterns may have on stream drainage.

Currently the Hocking Hills State Parks are primarily drained by westward flowing Pine and Queer Creeks, both draining into southwest flowing Salt Creek. Located in the drainage basins of these two streams are the districts where a majority of the gorges and hollows appear. According to Hall (1951, p. 8), "the drainage pattern is essentially dendritic, since the nearly horizontal structure of the bedrock exerts little control on the streams. Some of the tributaries to Salt Creek tend to be roughly parallel, which could possibly be due to the effects of glaciation, since the areas where the most pronounced parallel drainage is present are close to or within the glacial boundary."

But this seems unlikely since the only evidence of Illinoian and Wisconsin glacial till is in Salt Creek Township, northwest of the Park region and within the glacial boundary. Hall later states (1951, p. 10-15) that except along the larger valleys, glaciation has had little effect on the topography of Benton and Laurel Townships. The major influence of glaciation, the reversal of Salt Creek during Deep Stage, caused this stream to flow southwest into the Scioto River, making it the major stream draining the Park region to the east, and altering stream drainage patterns throughout the Park area (Stout and Lamb, 1938, p. 72, 77).

Since the ice sheets had little direct influence in the Park areas, except drainage alterations, it is unlikely the parallel valleys are the work of glaciation, but were shaped by jointing. Looking at a topographic map of Benton and Laurel Townships, the drainage pattern does not appear dendritic as Hall suggests, but the perpendicular intersection of side tributaries to their major streams indicates a modified rectangular or parallel patterned drainage, with right angle junctions similar to the perpendicular intersections of nonsystematic jointing.

To determine if jointing has regional control over stream development, the orientations of 135 primary and secondary tributaries to Pine and Queer

Creeks were recorded on a rose diagram (Fig. 23). Analysis of this data revealed two prominent trends. One is between N.65°-80°E., oriented the same as the nonsystematic joints in the area that are the extensions of the regional systematic jointing trends in Pennsylvania. The larger trend, oriented slightly west of north, compares with the perpendicular joint pattern in the region. The high frequency of streams parallel to the north trending

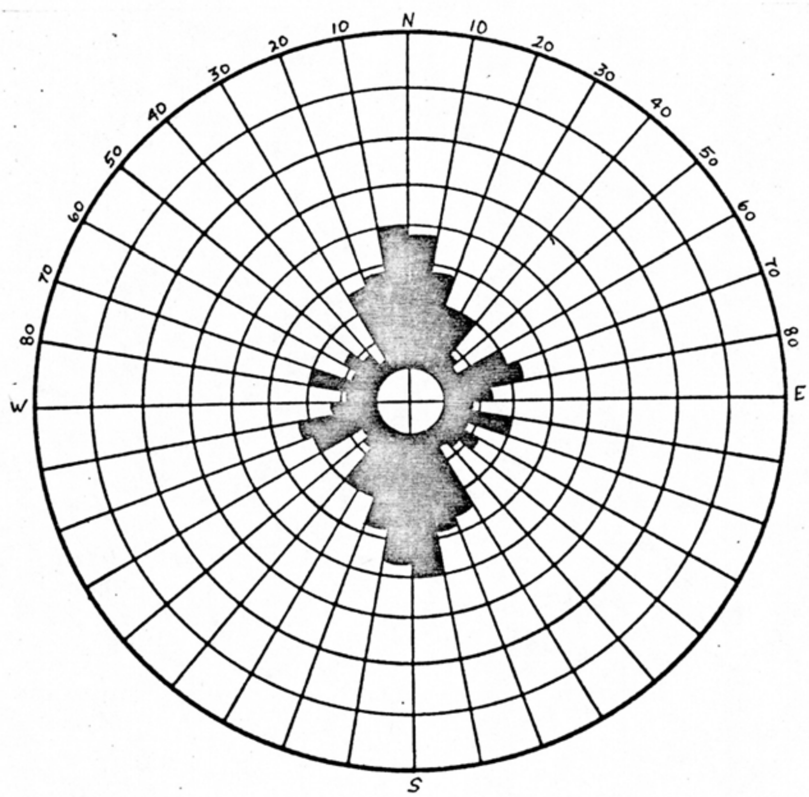


Figure 23. Rose diagram of streams in Benton and Laurel Townships showing orientation of 135 primary and secondary tributaries to Pine and Queer Creeks. One unit is equivalent to five streams.

joint set is a logical development of tne perpendicular intersection of patterned tributary drainage, since the major streams in the Parks follow the regional direction of the northeast trending joint set. These identical rose diagram (Fig. 6 and 23) orientations indicate that the stream patterns are consistent with the jointing patterns, in fact consequent upon them, and that jointing controls stream direction and the development of the topographic features in the Hocking Hills State Parks.

CHAPTER 3

CONCLUSIONS

The conclusions of this study on the jointing patterns in the area of the Hocking Hills State Parks are as follows:

1. Nonsystematic release joints in the Black Hand sandstone consist of two dominant perpendicular intersecting sets that are regionally oriented and the direct western extensions of Appalachian systematic joint sets in Pennsylvania.

2. Jointing patterns, formed during the Pleistocene uplift as residual stress, late release fractures, are related to the same tectonic horizontal compressive forces that previously created the Permian systematic joint sets and Appalachian axial folds in Pennsylvania.

3. Stream drainage, altered during the Pleistocene by glacial influence, is consequent upon and controlled by jointing patterns.

4. Jointing is responsible for the development of topographic features in the Black Hand sandstone of the Hocking Hills State Parks.

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